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SIMPLE MEASURES OF THE RAININESS OF A MONTH

By R. MURRAY and M. K. MILES

Introduction.—It has been recognized for a long time that the 'wetness' or 'raininess' of a month is not always well represented by the total rainfall of the month. Some other rainfall parameter might be a more meaningful indicator, but there would be little point in devising such a parameter unless it were more closely related to the synoptic character of the month than monthly rainfall and also readily understandable by recipients of long-range forecasts. Certain parameters, such as the sum of the cube roots of the daily rainfalls, might be useful for statistical purposes but would hardly satisfy either of the above provisos.

It is natural to consider another simple statistic, namely number of rain-days, especially since climatological data for this parameter are fairly plentiful. However, rain-days are officially defined as days with at least 0.2 mm of rain, and it may be contended that rainfall amounts of less than about 1 mm are too small for the purpose of representing the wetness of a day and for monthly forecasting purposes. It was therefore decided to examine the monthly rainfall at Kew in May in relation to rain-days defined as days with (1) at least 0.2 mm, (2) at least 1 mm, (3) at least 2 mm and (4) at least 3 mm of rainfall. In addition the association of the various rainfall parameters with circulation types as indicated by the monthly mean pressure maps was investigated. Kew rainfall was used simply because daily rainfall data were available. The period studied was the 78 years from 1873 to 1950.

Relationship between monthly rainfall and rain-days.—A correlation exists between monthly rainfall and the number of rain-days in the month, whatever threshold is taken to define a rain-day, as can readily be seen by plotting the two rainfall statistics on a scatter diagram.

Since the present practice is to attempt to predict monthly rainfall in terciles, it is useful to show the association between terciles of monthly rain and terciles of rain-days, by means of contingency tables. From frequency tables of monthly rainfall R and number of rain-days N (lower limit 0.2 mm), N_1 (lower limit 1 mm), N_2 (lower limit 2 mm) and N_3 (lower limit 3 mm) approximate tercile boundaries were readily obtained and contingency Tables I (a)–(d) were prepared.

TABLE I—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS

(a) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Lowest tercile ≤ 33 mm	Monthly rainfall R		Total
		Middle tercile 34-47 mm	Highest tercile ≥ 48 mm	
		<i>number of occasions</i>		
Lowest tercile ≤ 9 rain-days	18	4	2	24
Middle tercile 10-13 rain-days	7	16	5	28
Highest tercile ≥ 14 rain-days	1	6	19	26
Total	26	26	26	78

(b) Type N_1 (where rainfall is 1 mm or more per day)

Rain-days of type N_1	Lowest tercile ≤ 33 mm	Monthly rainfall R		Total
		Middle tercile 34-47 mm	Highest tercile ≥ 48 mm	
		<i>number of occasions</i>		
Lowest tercile ≤ 6 rain-days	18	3	1	22
Middle tercile 7-9 rain-days	8	17	4	29
Highest tercile ≥ 10 rain-days	0	6	21	27
Total	26	26	26	78

(c) Type N_2 (where rainfall is 2 mm or more per day)

Rain-days of type N_2	Lowest tercile ≤ 33 mm	Monthly rainfall R		Total
		Middle tercile 34-47 mm	Highest tercile ≥ 48 mm	
		<i>number of occasions</i>		
Lowest tercile ≤ 4 rain-days	19	5	1	25
Middle tercile 5-7 rain-days	7	16	5	28
Highest tercile ≥ 8 rain-days	0	5	20	25
Total	26	26	26	78

(d) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Lowest tercile ≤ 33 mm	Monthly rainfall R		Total
		Middle tercile 34-47 mm	Highest tercile ≥ 48 mm	
		<i>number of occasions</i>		
Lowest tercile ≤ 3 rain-days	19	8	0	27
Middle tercile 4-5 rain-days	7	10	6	23
Highest tercile ≥ 6 rain-days	0	8	20	28
Total	26	26	26	78

It will be noted that the numbers in each tercile are equal for monthly rainfall but only approximately so for rain-days owing to the limitations of the sample. It must be borne in mind when comparing the tables that the estimated terciles of rain-days suffer from this defect.

Broadly speaking there is a fairly close association between rainfall terciles and rain-days in all categories. It appears that in going from the lowest threshold of daily rainfall for defining a rain-day to the highest threshold the number of most anomalous cases (i.e. a highest tercile related to a lowest tercile and vice versa) is reduced from 3 in Table I(a) to 0 in Table I(d), but the cases in closest relationship (i.e. where terciles are related to terciles of the same type) are reduced from 53 in Table I(a) to 49 in (d). Actually Tables I(b) and (c) suggest a slightly better relationship between the monthly rainfall and number of rain-days than do Tables I(a) and (d), but the differences between the tables are marginal.

Relationship between rainfall parameters and monthly mean pressure anomaly at Kew.—Were it possible to predict monthly mean pressure anomaly either quantitatively or qualitatively by virtue of forecasting the circulation character of the month, it would be desirable to know the relationship between such anomalies and the various rainfall parameters in terciles. There is a fairly good relationship between pressure anomaly (Δp) and each of the various rainfall parameters. The present sample suggests that N (i.e. ≥ 0.2 mm) is slightly more closely associated with Δp than are either N_3 (i.e. ≥ 3 mm) or R . Tables II and III show the relationship between the pressure anomaly and N and R respectively.

TABLE II—KEW RAIN-DAYS IN MAY RELATED (IN TERCILES) TO MONTHLY MEAN

Monthly mean pressure anomaly Δp	PRESSURE ANOMALY			Total
	Rain-days of type N			
	Lowest tercile ≤ 9	Middle tercile 10-13 <i>number of occasions</i>	Highest tercile ≥ 14	
≤ -2 mb	1	4	15	20
-1 to +1 mb	8	14	8	30
$\geq +2$ mb	15	10	3	28
Total	24	28	26	78

Rain-days of type N have 0.2 mm or more of rainfall per day.

TABLE III—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO MONTHLY MEAN

Monthly mean pressure anomaly Δp	PRESSURE ANOMALY			Total
	Monthly rainfall R			
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
≤ -2 mb	0	8	12	20
-1 to +1 mb	10	10	10	30
$\geq +2$ mb	16	8	4	28
Total	26	26	26	78

Relationship between rainfall parameters and monthly circulation type.—The mean surface pressure maps for each May were classified subjectively according to circulation type over the British Isles. The curvature and direction of the mean isobars and the general pressure level were used as a guide in making the classifications. There were three broad types, namely (i) cyclonic, (ii) anticyclonic and (iii) others, with sub-divisions such as cyclonic westerly, anticyclonic north-westerly and so on.

(i) *Cyclonic types.*—Table IV (a)–(d) shows the association between R and each of N , N_1 , N_2 and N_3 when the monthly mean surface-pressure maps are classified as cyclonic over the British Isles.

Table IV speaks for itself. Monthly rainfall is closely related to rain-days in each case in cyclonic circulation types. There is a suggestion, however, that the

TABLE IV—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN CYCLONIC CIRCULATIONS

(a) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 9 rain-days	0	0	0	0
Middle tercile 10-13 rain-days	0	2	0	2
Highest tercile ≥ 14 rain-days	0	3	15	18
Total	0	5	15	20

(b) Type N_1 (where rainfall is 1 mm or more per day)

Rain-days of type N_1	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 6 rain-days	0	0	0	0
Middle tercile 7-9 rain-days	0	3	1	4
Highest tercile ≥ 10 rain-days	0	2	14	16
Total	0	5	15	20

(c) Type N_2 (where rainfall is 2 mm or more per day)

Rain-days of type N_2	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 4 rain-days	0	2	0	2
Middle tercile 5-7 rain-days	0	1	2	3
Highest tercile ≥ 8 rain-days	0	2	13	15
Total	0	5	15	20

(d) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 3 rain-days	0	1	0	1
Middle tercile 4-5 rain-days	0	2	2	4
Highest tercile ≥ 6 rain-days	0	2	13	15
Total	0	5	15	20

best association is between N and R and the least good is between N_3 and R . It is noteworthy, though possibly not surprising, that the lowest terciles of monthly rain apparently never occur in association with the lowest terciles of rain-days in cyclonic types. Nor are the lowest terciles of monthly rain associated with the highest terciles of rain-days, or vice versa.

(ii) *Anticyclonic types*.—The relationships between R and the parameters N , N_1 , N_2 and N_3 for anticyclonic types are given in Table V(a)–(d).

The association between monthly rainfall and rain-days for anticyclonic types is fairly good for each category of rain-day but not so strikingly close as

TABLE V—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN ANTICYCLONIC CIRCULATIONS

(a) Type N (where rainfall is 0.2 mm or more per day)				
Rain-days of type N	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	
		number of occasions		
Lowest tercile ≤ 9 rain-days	16	1	1	18
Middle tercile 10–13 rain-days	2	5	3	10
Highest tercile ≥ 14 rain-days	0	1	1	2
Total	18	7	5	30
(b) Type N_1 (where rainfall is 1 mm or more per day)				
Rain-days of type N_1	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	
		number of occasions		
Lowest tercile ≤ 6 rain-days	15	1	1	17
Middle tercile 7–9 rain-days	3	5	1	9
Highest tercile ≥ 10 rain-days	0	1	3	4
Total	18	7	5	30
(c) Type N_2 (where rainfall is 2 mm or more per day)				
Rain-days of type N_2	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	
		number of occasions		
Lowest tercile ≤ 4 rain-days	16	2	1	19
Middle tercile 5–7 rain-days	2	5	1	8
Highest tercile ≥ 8 rain-days	0	0	3	3
Total	18	7	5	30
(d) Type N_3 (where rainfall is 3 mm or more per day)				
Rain-days of type N_3	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34–47 mm	Highest tercile ≥ 48 mm	
		number of occasions		
Lowest tercile ≤ 3 rain-days	14	3	0	17
Middle tercile 4–5 rain-days	4	2	3	9
Highest tercile ≥ 6 rain-days	0	2	2	4
Total	18	7	5	30

for the cyclonic circulations. The cyclonic circulation type has most cases in the top terciles whereas the anticyclonic type has most cases in the lowest terciles with an important minority of cases in the highest terciles. It is of interest to observe that the raininess parameter N gives the lowest number of cases in its top tercile (2 in Table V(a)) while R gives 5 in its top tercile in all tables.

(iii) *Other types (neither cyclonic nor anticyclonic).*—Examples of this miscellaneous group are easterly, north-westerly, weak westerly, col types and so on. The association between rainfall and rain-days for these types is illustrated in Table VI(a) and (b).

TABLE VI—KEW RAINFALL IN MAY RELATED (IN TERCILES) TO RAIN-DAYS IN NON-CYCLONIC AND NON-ANTICYCLONIC TYPES

(a) Type N (where rainfall is 0.2 mm or more per day)

Rain-days of type N	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 9 rain-days	2	3	1	6
Middle tercile 10-13 rain-days	5	9	2	16
Highest tercile ≥ 14 rain-days	1	2	3	6
Total	8	14	6	28

(b) Type N_3 (where rainfall is 3 mm or more per day)

Rain-days of type N_3	Monthly rainfall R			Total
	Lowest tercile ≤ 33 mm	Middle tercile 34-47 mm <i>number of occasions</i>	Highest tercile ≥ 48 mm	
Lowest tercile ≤ 3 rain-days	5	4	0	9
Middle tercile 4-5 rain-days	3	6	1	10
Highest tercile ≥ 6 rain-days	0	4	5	9
Total	8	14	6	28

In each case the middle tercile of R , N , N_1 , N_2 and N_3 is the most frequent one and the most common association is between the middle tercile of monthly rain and the middle tercile of rain-days. However, each tercile of N_3 is nearly equally likely.

Anomalous relationships between total rainfall and rain-days.—

For this purpose anomalous cases were taken as those in which there was at least one tercile difference between the terciles of monthly rain R and rain-days N , N_1 , N_2 and N_3 . The anomalous behaviour of monthly rainfall relative to rain-days is thus either (i) too much rain relative to the rain-days or (ii) too little rain relative to the rain-days.

(i) *Terciles of R higher than terciles of N , N_1 , N_2 or N_3 .*—There were 11 of N , 8 of N_1 , 11 of N_2 and 14 of N_3 . In no case did the same May occur in all the categories of rain-days. In other words in going from threshold 0.2 mm to threshold 3 mm in defining a rain-day anomalous cases were made normal at the expense

of bringing in new anomalous months. A variety of circulation types was associated with the anomalous relationships but some rough groupings can be discerned.

For thresholds 0.2 mm (N) and 1 mm (N_1) there is a notable scarcity of cyclonic types (0 for N and 1 for N_1) and a predominance of types involving easterly flow (i.e. south-east, east and north-east) with Δp at Kew rarely positive. Several other cases are associated with rather weak gradients over the British Isles.

For thresholds 2 mm and 3 mm cyclonic types are nearly as frequent as types involving easterly flow and these two make up at least half of the total cases. Others are mainly those associated with rather weak gradients over the British Isles.

(ii) *Terciles of R lower than terciles of N , N_1 , N_2 and N_3 .*—There were 14 of N , 14 of N_1 , 12 of N_2 and 15 of N_3 . In this case five Mays persisted as anomalous in changing from thresholds 0.2 mm to 3 mm for the definition of a rain-day.

For thresholds 0.2 mm and 1 mm the circulation types are mixed, including cyclonic and anticyclonic types. However there is a scarcity of types involving easterly flow (contrast this with anomalous cases (i)) and the most common type involves north-westerly or northerly flow.

For thresholds 2 mm and 3 mm the circulation types are again mixed but the difference between the frequency of easterly and north-westerly or northerly types has disappeared. Threshold 3 mm brings in the highest number of anticyclonic types.

Concluding remarks.—This analysis covers a limited field. Nevertheless it does not seem that there is any strong evidence for replacing monthly rainfall by rain-days whichever threshold is used to define the latter. There is certainly nothing to suggest that the defining threshold for a rain-day should be raised to 2 mm or 3 mm, and little evidence that it would be worthwhile to use 1 mm rather than 0.2 mm especially since much of the available data about rain-days is based on the lowest threshold.

The analysis does, however, suggest that there is a broad relationship between monthly rainfall or rain-days and the circulation types. In cases where the monthly circulation over the British Isles can be classified as cyclonic, the monthly rainfall and rain-days are closely related to each other and are mostly in the top terciles. For anticyclonic circulations, monthly rainfall and rain-days are mostly in the lower terciles and the association between them is only slightly less good. For the miscellaneous circulation types (i.e. non-cyclonic and non-anticyclonic) the association is least satisfactory.

The anomalous cases, that is the cases with too much or too little rain relative to rain-days, are not clear-cut, but some rough classification according to circulation types can be made.

It is thought that provided the broad circulation type can be predicted the factual information in this note should assist the forecaster in assessing whether the terciles of rainfall are adequate by themselves in describing the rainfall character of the whole month or need some qualification by referring to terciles of rain-days.

No doubt other months will show anomalous rainfall relationships of various kinds according to the circulation pattern, but these would need to be investigated.

OROGRAPHIC EFFECTS AT ACKLINGTON

By A. GRAY and W. J. STEWART

Introduction.—In situations of westerly winds the flow to the east of the Pennines and the Cheviot Hills, on the border of Scotland and England, may contain lee waves such as are described by Förchtgott¹ and Corby,² and orographic effects may give rise to lenticular cloud and low-level turbulence including marked variability of surface winds. Several cases have been observed at Acklington, Northumberland (55°18'N 01°38'W, 138 feet above M.S.L.), and this note discusses an occasion when the surface wind showed rapid variations and when low-level turbulence was reported from aircraft. The main areas of high ground around Acklington can be seen in Figure 1.

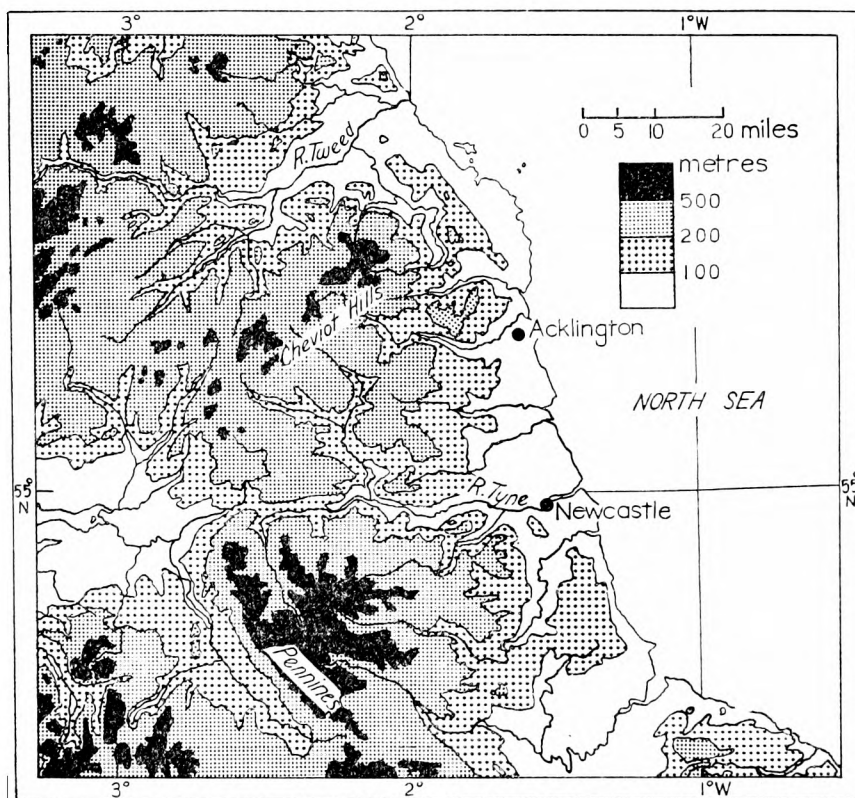


FIGURE 1—RELIEF MAP OF THE ACKLINGTON AREA

Orographic effects on 31 January 1962.—On this occasion there were warm-sector conditions with a strong south-westerly flow over the area. The synoptic situation is shown in Figure 2. Cloud, surface wind and aircraft observations have been summarized as follows:

(i) *Cloud observations.*—Between 0900 and 1030 GMT altocumulus and altostratus were reported in two definite layers—3/8 altocumulus with base 10,000 feet and 7/8 altostratus with base 15,000 feet. The altocumulus had no marked lenticular pattern at this time but later in the day (1400 to 1700 GMT) two small patches, one north and one south of the airfield, were observed with base about 8000 feet and tops about 10,000 feet. These small patches amounted

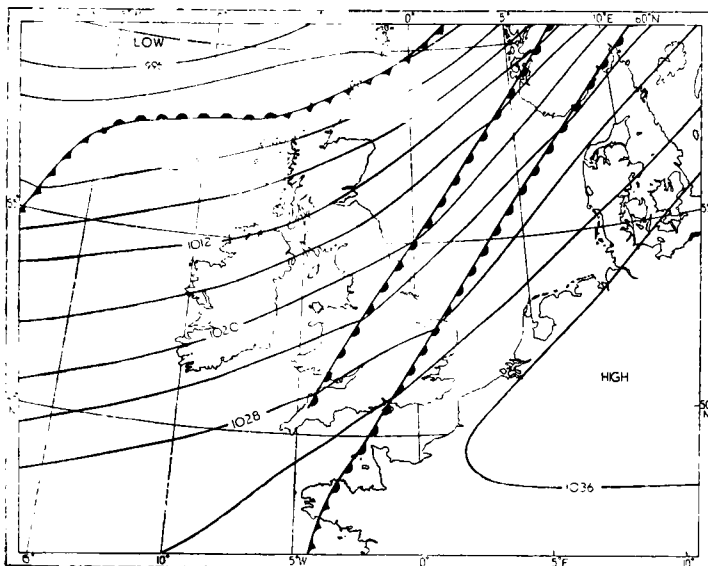


FIGURE 2—SYNOPTIC SITUATION AT 0600 GMT ON 31 JANUARY 1962

to about 1/20 of the total cloud cover. Stratus and stratocumulus were also present during this time (amount 3/8 and base 1400 feet), mainly between Acklington and the coast, some three miles further east. This cloud was too distant to determine whether or not it was a rotor type of cloud.

(ii) *Surface wind observations.*—The surface wind measurement at Acklington is made by a cup-generator and remote-reading direction-indicator. Both units produce instantaneous readings but no permanent record. The surface winds observed between 0900 and 1030 GMT are shown in Table I. The rapid variations were probably caused by orographic effects.

TABLE I—VARIATION OF SURFACE WINDS ON 31 JANUARY 1962

Time GMT	Wind degrees	knots	Time GMT	Wind degrees	knots
0900	200	7	1000	rapid veer in seconds to	
0940	150	8		220	6
0950	150	10	1010	230	18
0952	150	10	1025	240	25 gusts to 40
0955	050	6			

(iii) *Aircraft observations.*—During the morning experienced pilots were engaged in local flying around Acklington in light aircraft. These pilots reported extreme turbulence in the height band 440 to 1640 feet above M.S.L. (300 to 1500 feet above ground). One pilot stated that he had no effective control over the aircraft. It is significant that this coincided with the period when the surface wind direction was far removed from what would be predicted, and when the speed was light.

Discussion.—The general temperature and wind structures were similar to those required for rotor streaming of the type described by Förchtgott and Corby. The vertical temperature structures at Aldergrove and Aughton are shown in Figures 3 (a) and (b) as well as the wind speed resolved along the wind direction at 900 metres (about 920 mb), i.e. roughly perpendicular to a nearby ridge of hills. In each case the wind profile shows a layer of strong

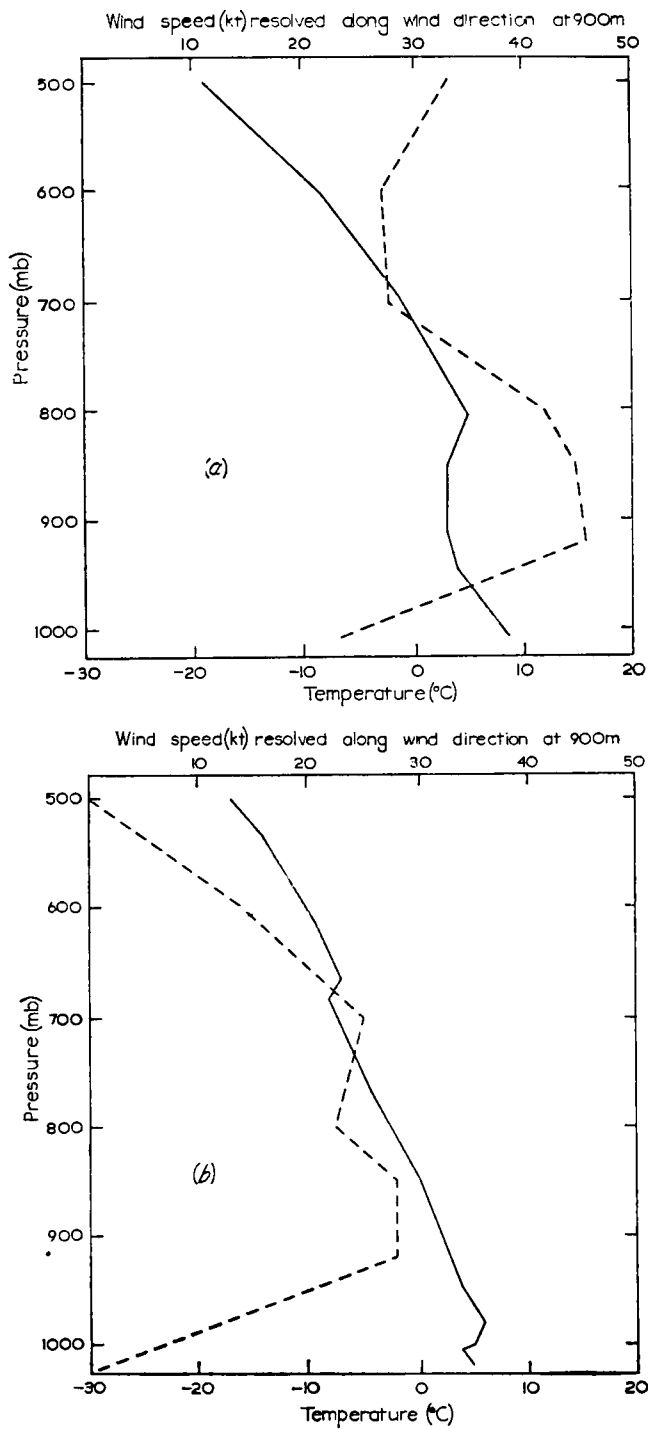


FIGURE 3—VERTICAL TEMPERATURE STRUCTURE AND WIND SPEED RESOLVED ALONG THE WIND DIRECTION AT 900 METRES AT 0000 GMT ON 31 JANUARY 1962

——— Temperature in °C, - - - wind speed in knots resolved along the wind direction at 900 metres.

(a) Aldergrove

(b) Aughton

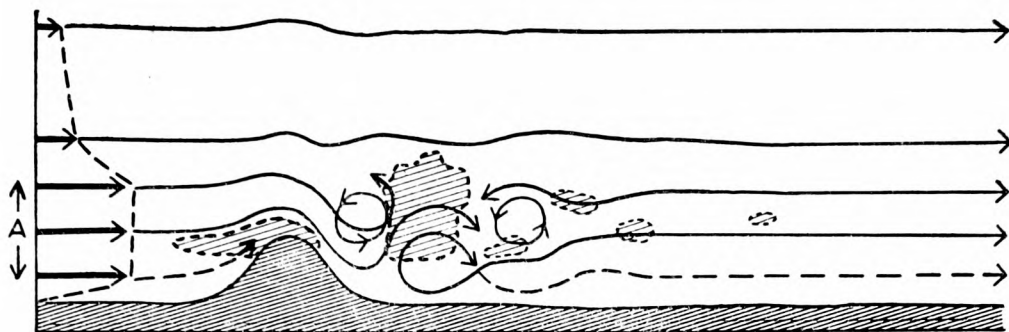


FIGURE 4—ROTOR STREAMING (AFTER FÖRCHTGOTT¹)
 'A' indicates streaming layer and bold arrows on the left show the wind profile.

winds with lighter flow above and below similar to that shown in Figure 4. The Aldergrove example also shows a very stable temperature structure in the strong wind flow.

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ASSOCIATION OF CLEAR-AIR TURBULENCE WITH 300 MB CONTOUR PATTERNS

By A. A. BINDING

Introduction.—Clear-air turbulence (CAT) usually in association with jet streams has been forecast at London (Heathrow) Airport for several years using wind shear criteria and actual reports from aircraft as the basis for the prognosis. Some forecasting failures have occurred because in the event reports have been received from areas not indicated as favourable and other apparent failures have occurred because in the event reports have been lacking from quite large areas which were indicated as favourable.

Experience at London Airport had indicated a possible connexion between curvature of the flow and turbulence, and this investigation was made to determine to what extent 300 mb contour patterns might be associated with CAT and whether such associations could be of use in forecasting. Several cases of CAT were found to be in positions remote from any jet-stream core, confirming that it was not possible to forecast all CAT on jet-stream considerations alone. These non jet-stream cases were associated with identifiable 300 mb contour patterns, and it was found possible in the year under review to associate jet-stream cases as well with 300 mb contour patterns, thus indicating the possibility of forecasting CAT primarily by examining data visible on one prontour chart alone.

Subsequent to this investigation a report¹ on CAT over America has been published containing the following statement "Of the 5623 reports of moderate or greater turbulence during the year 36 per cent were within 150 miles to the left or the cold side of the jet, 28 per cent were within 150 miles to the right of the jet and 36 per cent were more than 150 miles from any jet (non-jet cases). In any study or forecast of turbulence limited to 150 miles to the left or cold side of the jet 64 per cent of all the occurrences would have been neglected."

The data.—From a record maintained at London Airport of reports of CAT from eastbound and westbound aircraft on transatlantic routes, all reports of CAT of moderate or greater severity were extracted for the year August 1962 to July 1963 for areas over the sea (topographical influence thereby being largely eliminated) and plotted on the appropriate 300 mb chart for either 0000 GMT or 1200 GMT, since these are the only charts fully analysed. In a few cases where doubts arose some detailed redrawing of the 300 mb contours was done by making use of winds reported from aircraft. Such winds were used in the belief that if a large number of similar winds were reported, a wind-field of the kind indicated was probable. The total area inspected was bounded by latitudes 40°N and 65°N and longitudes 5°W and 65°W .

A report which gave a distance over which CAT was experienced was arbitrarily counted as two reports for arithmetical purposes, one at each end of the line quoted.

All of the reports were from transport aircraft, mostly civil, and turbulence was reported in subjective terms such as slight (or feeble), moderate and severe or combinations of them. It was considered that only severity moderate or greater would be of much interest as feeble or slight intensity would usually refer to 'cobblestone' turbulence which has no operational significance.

Approximately 100,000 in-flight reports were received from transatlantic flights during the year, i.e. about 130 reports per day, and these are necessarily within 6 hours of either 0000 or 1200 GMT. In-flight reports are normally made at intervals of 10° longitude and mention of turbulence is required only if it occurred within the 10 minutes preceding the report, although some crews provide reports in excess of these requirements. Thus there are usually 5 or more reports from each flight.

It is noteworthy that there were only 27 reported cases of severe CAT and 230 of severity moderate or greater in a total of 430 cases for all kinds of CAT, representing 0.4 per cent of the total number of in-flight reports. In comparing these figures with those in earlier reports it is important to remember that, for the period under discussion, there were about 20 flights above 30,000 feet for every flight below, whereas most earlier reports have examined observations with a distinct bias towards low-level flights. Clodman, Morgan and Ball² quote turbulence data for 849 Pan American and Trans World jet-engined flights over the North Atlantic for a 3-month period in 1960, when turbulence was reported on only 21 flights. Assuming that there were no more than 21 turbulence reports and that each flight made 5 in-flight reports, the frequency of turbulence was 0.5 per cent of the total number of reports.

Associations of CAT with 300 mb contour patterns and instability areas.—The 230 reports of CAT of severity moderate or greater plotted for the year under consideration could be classified under three headings according to the 300 mb contour pattern and the occurrence of instability areas.

- (i) *Ridge type.*—As many as 140 reports were in regions where the contours were anticyclonically curved, and where wind speeds and curvatures were about the theoretical limiting values. These were determined using a scale designed by Jefferson³ to show the expected limitation of anticyclonic curvature of streamlines on an upper air chart. Additionally, wind shear was anticyclonic except possibly in a few cases of very sharp ridging where shear was apparently small, and difficult to assess.

- (ii) *Sharp trough type*.—Another 62 cases occurred in sharp troughs, defined arbitrarily as troughs which would, on passage, produce a wind shift of at least 90° . Turbulence in this situation is already well documented, for example by Briggs.⁴
- (iii) *Instability area type*.—Only 28 cases occurred in areas with marked cyclonic curvature of the contours and cyclonic shear. Although reports of great cumulonimbus activity were not always available from these areas, in 9 cases they were and in all 28 cases the thickness pattern indicated that thunderstorms would probably have been forecast. It is suggested that at least in the troposphere turbulence is likely above cumulonimbus tops, while in the stratosphere damping could lead to turbulent wave motions.

Persistence of turbulent situations.—It was found convenient in the study of persistence to define an occasion as a period in which CAT was reported but which was preceded and followed by at least 12 hours without a report of moderate or severe CAT in any part of the corresponding 300 mb pattern. Out of 116 such periods there were, in the year, 102 occasions of less than 12 hours duration, 11 which lasted for more than 12 hours but less than 24 hours and the remaining 3 occasions lasted for more than 24 hours but less than 36 hours. No persistence longer than 36 hours was recorded. The generally low incidence of turbulence may partly account for this apparent lack of persistence but, whatever the reason, it is clear that too much dependence upon actual reports is to be avoided in the preparation of a forecast for more than 12 hours ahead.

Classification of occurrences of CAT.—Table I was prepared by including all reports of CAT of moderate or greater severity associated with:

anticyclonic curvature of the wind,
sharp troughs,
and thermal instability areas.

In each category the reports were also classified according to altitude. The weight of reports around 35,000 feet largely reflects an operational altitude preference, about 20 flights being made above 30,000 feet for each flight below.

TABLE I—CLASSIFICATION OF OCCURRENCES OF CAT

Altitude feet	Ridge	Sharp trough	Instability area
20,000–25,000	1	3	11
26,000–30,000	5	4	0
31,000–35,000	82	44	14
36,000–40,000	52	11	3
All altitudes	140 (61 %)	62 (27 %)	28 (12 %)

The table shows that at the lower levels CAT occurred mostly in cyclonic patterns whereas at higher levels there were about twice as many occurrences in ridge conditions as in cyclonic conditions.

The ridge type.—This is a situation not generally recognized as being associated with clear-air turbulence, yet it accounts for 61 per cent of the reports received, and if the year's observations are at all typical it is clearly a situation that merits further consideration.

Theoretical work indicates^{5,6} that the vertical component of absolute vorticity must be positive if the flow is to remain stable, i.e. for inertial stability:

$$\frac{V}{r} - \frac{\partial V}{\partial n} + f > 0$$

where V = wind velocity

r = radius of curvature of the streamlines

$\partial V/\partial n$ = horizontal wind shear along the normal to the streamline, the positive direction of the normal being taken to the left of the flow

f = Coriolis parameter.

In the anticyclonic case r is negative, and $\partial V/\partial n$ is positive. The term $V/r - \partial V/\partial n$ is then a negative quantity and when it is numerically equal to f the stability becomes critical. An increase in either V/r or $\partial V/\partial n$ after this critical stage has been reached will lead to inertial instability.

A developing depression frequently causes rapid formation or strengthening of the associated warm-front jet stream with simultaneous rapid lateral movement. In these circumstances if the curvature remains sensibly constant in the upper ridge ahead of the deepening low, increasing V will lead to increased instability especially where the anticyclonic wind shear increases. An increase in anticyclonic curvature can also cause increased instability and this condition sometimes arises well to the right of the jet-stream core.

Illustrations.—Some examples of the types of 300 mb contour patterns associated with CAT are reproduced at Figures 1 to 12.

Turbulence observations are located by an X or two X's joined with a pecked line X- - -X. The degree of turbulence is abbreviated—MOD = moderate, SEV = severe, MOD/SEV = moderate to severe, OCC MOD = occasionally moderate—with the altitude in hundreds of feet to the right in brackets and the time GMT below when the report refers to a position X. When the information refers to a line X- - -X the details are written along the line.

Maximum theoretical curves for appropriate geostrophic wind speeds are drawn as necessary by a dotted line with the maximum speed in knots noted alongside.

Figure 1 illustrates the typical sharpening ridge situation.

Figures 2, 3 and 4 comprise a consecutive series of ridge type occurrences.

Figures 5 and 6 show two occurrences during the advance of a ridge.

Figure 7 shows a case of turbulence in a light anticyclonic gradient.

Figures 8 to 10 show well-known sharp trough situations, the first two being a sequence. Around 50°N in Figure 10 the trough was at about 42°W at 0600 GMT and 38°W at 1800 GMT.

Figure 11 shows a situation which could be classified sharp trough or instability, and Figure 12 instability. In these two cases estimated values of the altitude of the tropopause in hundreds of feet are shown at the locations of each turbulence report.

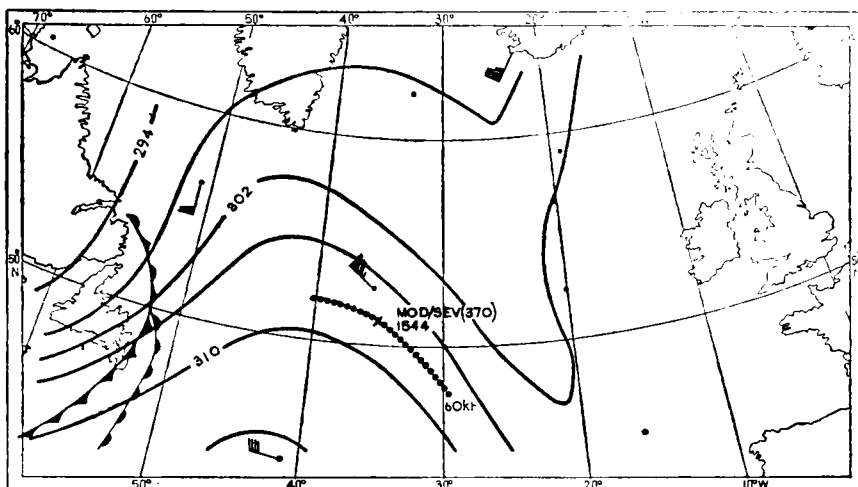


FIGURE 1—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 19 SEPTEMBER 1962
Contours are in hundreds of feet.

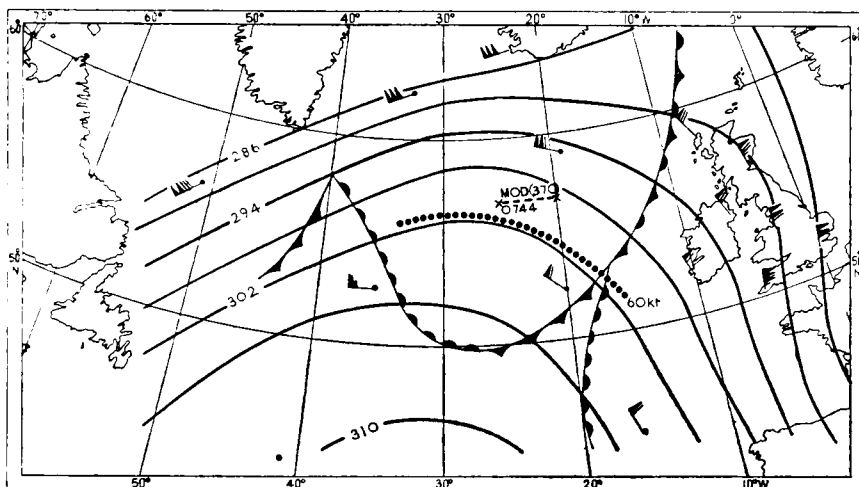


FIGURE 2—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 13 DECEMBER 1962
Contours are in hundreds of feet.

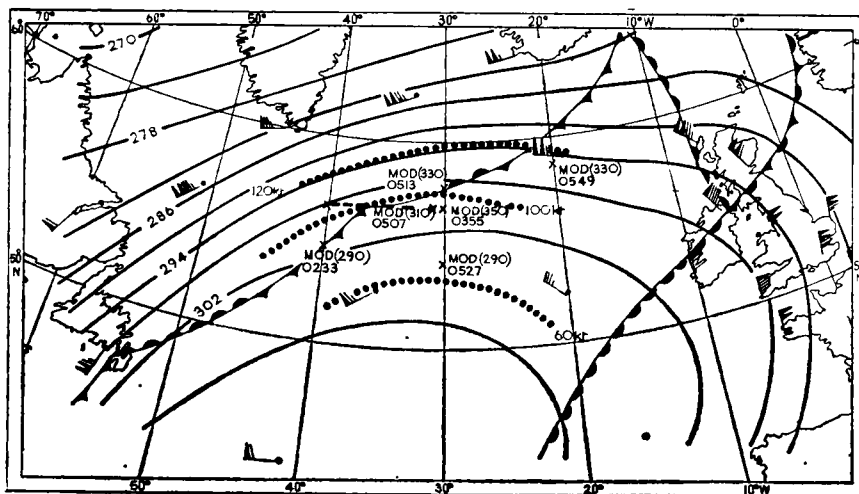


FIGURE 3—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
0000 GMT, 14 DECEMBER 1962
Contours are in hundreds of feet.

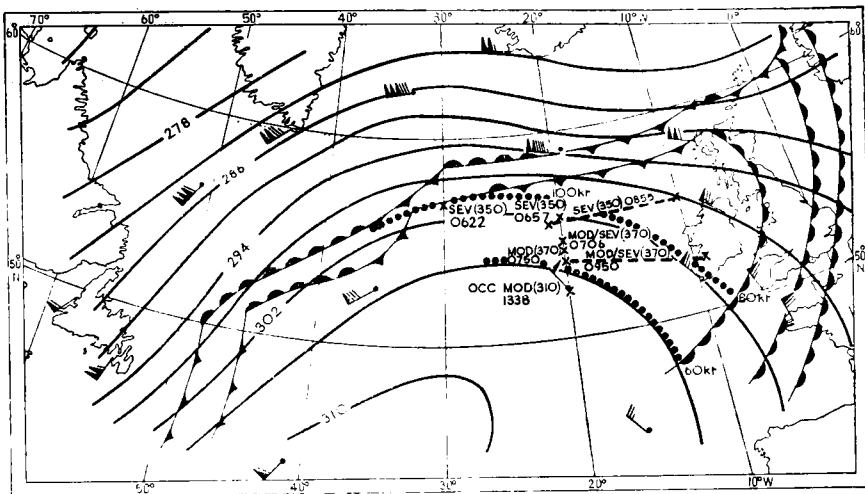


FIGURE 4—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 14 DECEMBER 1962
Contours are in hundreds of feet.

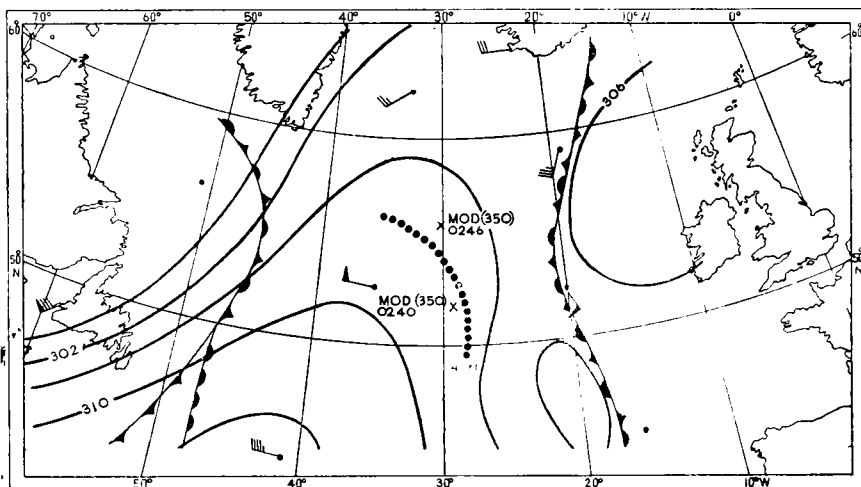


FIGURE 5—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
0000 GMT, 20 SEPTEMBER 1962
Contours are in hundreds of feet.

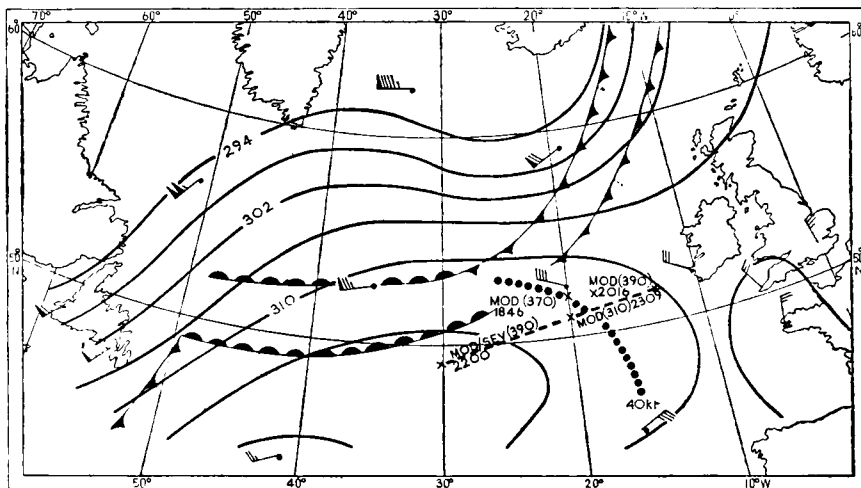


FIGURE 6—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
0000 GMT, 22 SEPTEMBER 1962
Contours are in hundreds of feet.



Photograph by G. J. Jefferson

PLATE I—CUMULUS HEADS SHOWING 'ANVIL PUFFS' AT NICOSIA AT 1530 GMT,
7 JUNE 1964
See page 23.

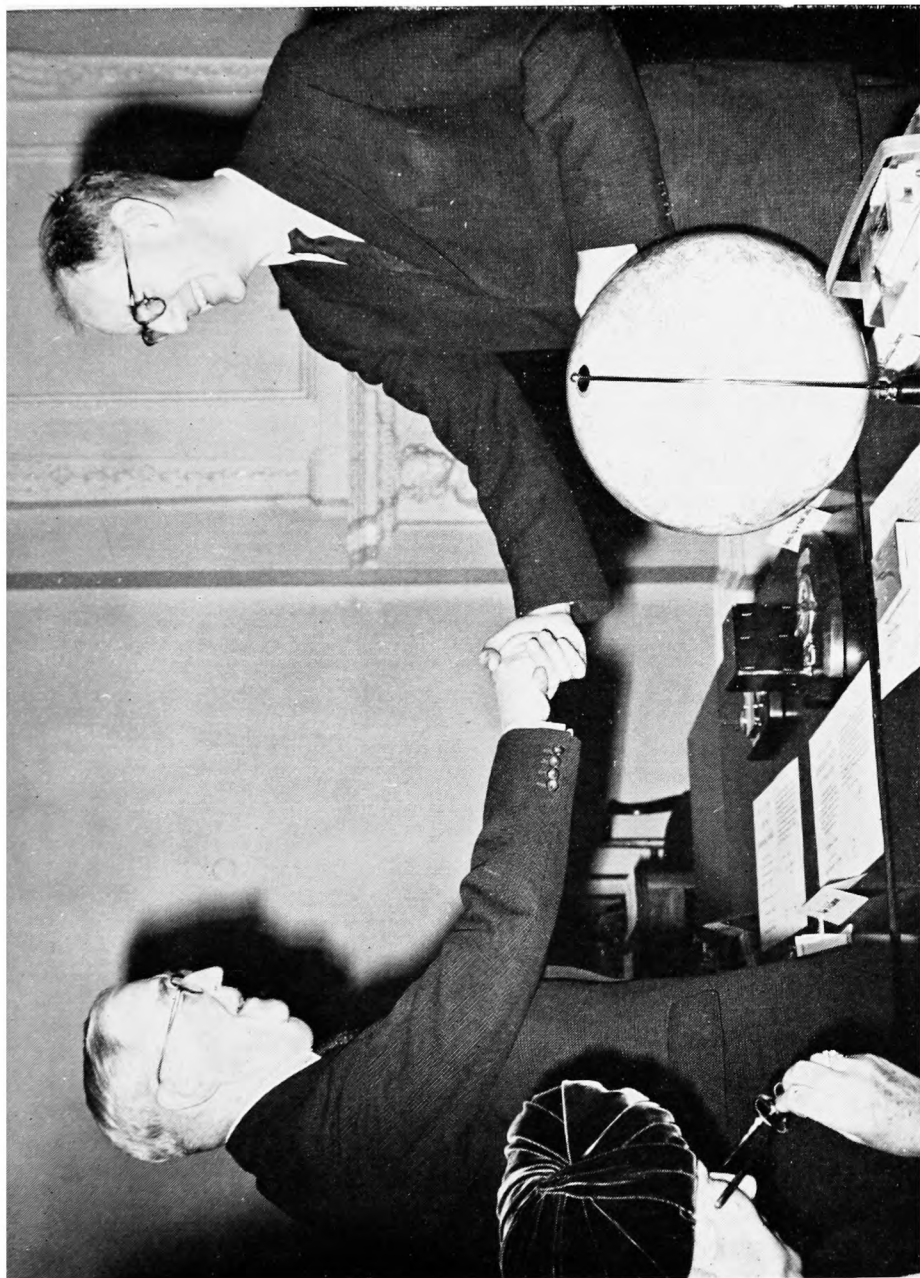


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PLATE II—PRESENTATION OF THE L. G. GROVES MEMORIAL PRIZES AND AWARDS

ON 6 NOVEMBER 1964

Left to right: Air Marshal Sir Christopher Hartley, Flight Lieutenant D. C. Evers, Dr. K. H. Stewart, Major K. J. Groves, Mrs. Groves, ex-Flight Sergeant G. F. Earnshaw and Master Pilot R. E. Purdue (see page 30).



Crown copyright

PLATE III—MAJOR K. J. GROVES PRESENTING THE MEMORIAL PRIZE FOR METEOR-
OLOGY TO DR. K. H. STEWART

See page 30.



Photograph by W. G. Pendleton

PLATE IV—HEAVY SNOWFALL AT BRACKNELL ON THE NIGHT OF 15-16 MARCH 1964

The snow as shown in the photograph was about 6 to 8 inches deep on the trees. Many of the branches had been bent to the ground by the heavy weight of snow and some had even been broken.

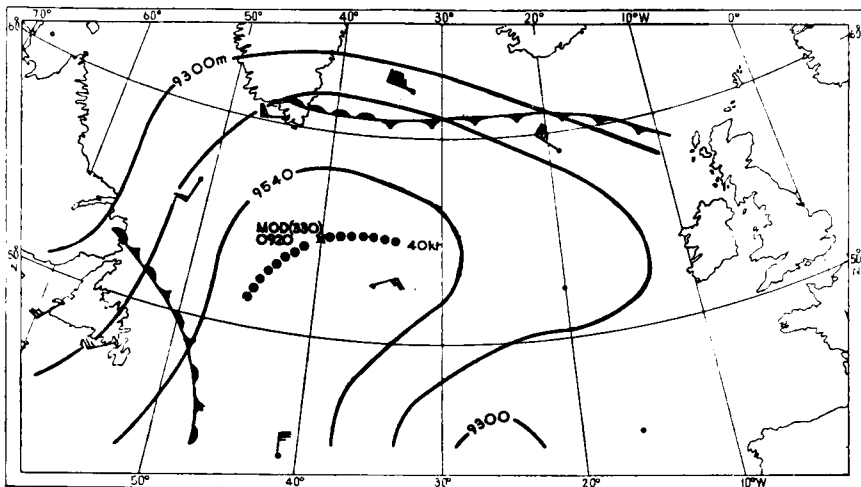


FIGURE 7—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 8 JULY 1963
Contours are in metres.

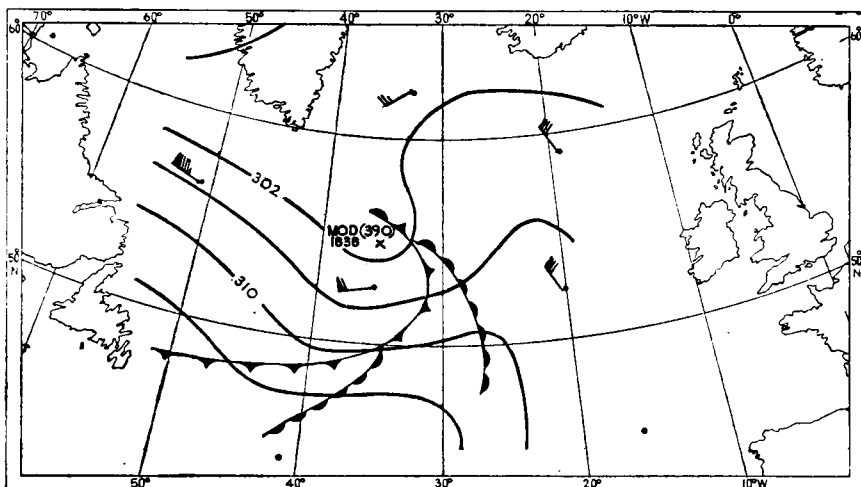


FIGURE 8—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 13 AUGUST 1962
Contours are in hundreds of feet.

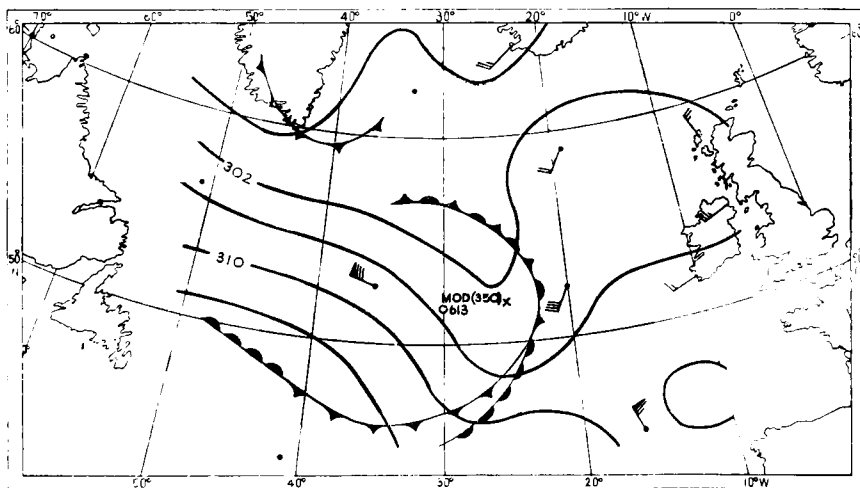


FIGURE 9—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
0000 GMT, 14 AUGUST 1962
Contours are in hundreds of feet.

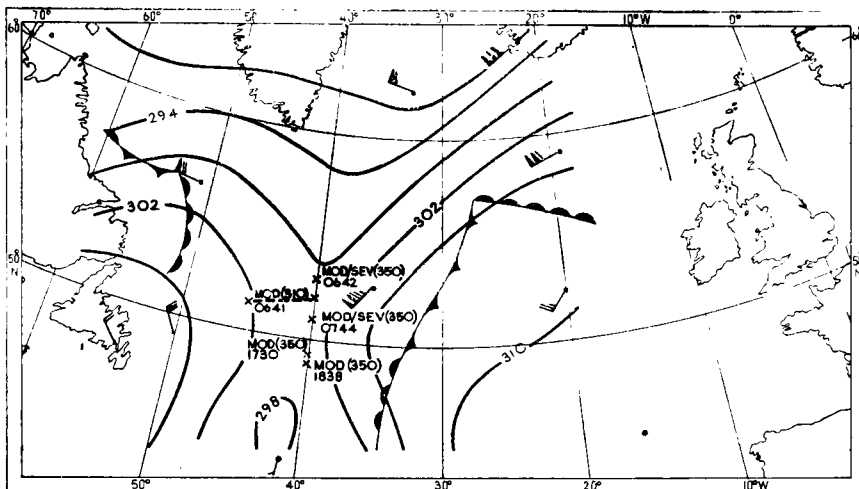


FIGURE 10—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 17 OCTOBER 1962
Contours are in hundreds of feet.

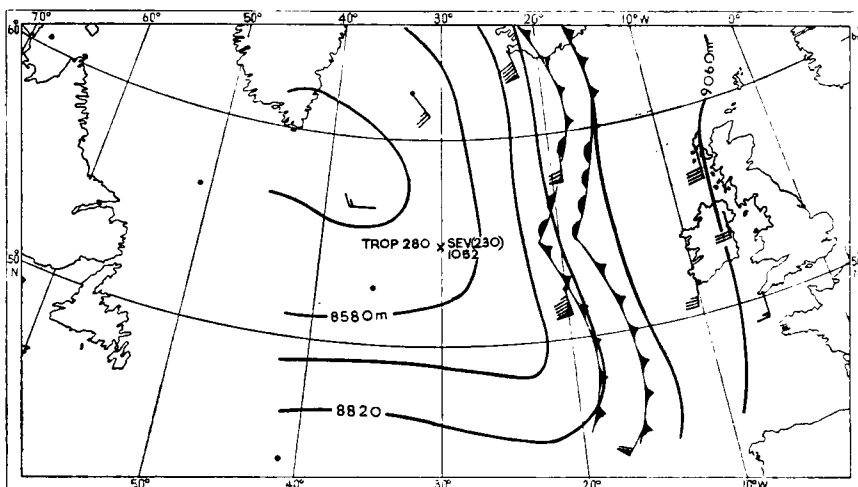


FIGURE 11—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS AT
1200 GMT, 3 MARCH 1963
Contours are in metres. The height of the tropopause (TROP) is given in hundreds of feet.

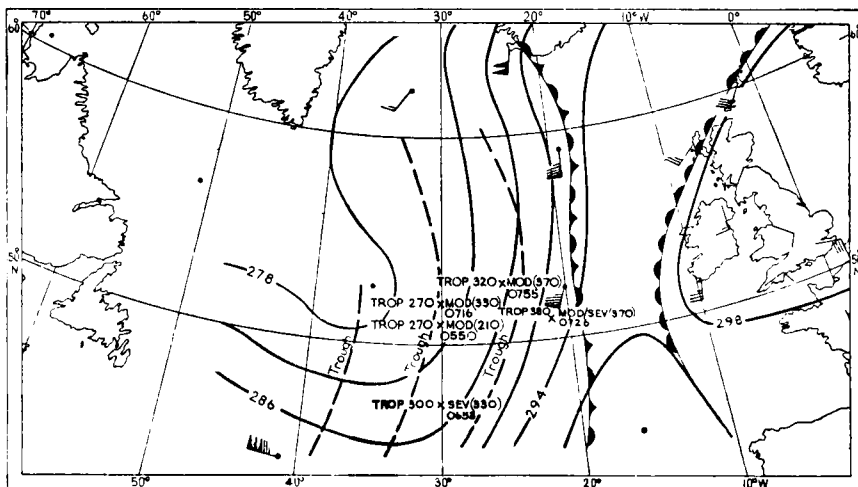


FIGURE 12—CONTOURS AND RADAR WINDS AT 300 MB AND SURFACE FRONTS
AND TROUGHS AT 1200 GMT, 27 FEBRUARY 1963
Contours are in hundreds of feet.
The height of the tropopause (TROP) is given in hundreds of feet.

Conclusion.—During the year under consideration, using the 300 mb ridge and trough patterns and instability areas, and assuming accurate forecasts of patterns, about 900 separate areas of possible moderate or severe CAT would have been forecast on the 730 charts involved. Of these areas only 12 per cent contained in the event reports of CAT of severity moderate or greater, but all such occurrences were forecast. Forecasting CAT to occur only near jet-stream cores, with a preference for the cold side would probably have required about the same number of forecast areas, but most of the ridge type occurrences would in the event have been missed.

The fact that all reports of CAT of severity moderate or greater over the North Atlantic during the year could be associated with three types of 300 mb contour pattern, whether or not the turbulence was due to jet-stream influences, suggests a simple forecasting guide which could be used to supplement existing methods.

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551.510.534:551.521.17

THE HIGH ATMOSPHERE

By R. FRITH

Impinging on the earth's atmosphere, and responsible in one way or another for the whole of meteorology, is a stream of solar radiation. The earth's atmosphere is almost completely transparent to most of this radiation, but some of it is absorbed, principally at high levels and the absorbed radiation supplies energy for meteorological processes at these levels. Absorption of radiation by a gas is a very selective affair, and each constituent of the atmosphere absorbs radiation only in certain wavebands. These absorption bands are different from gas to gas, but bands for different gases may overlap. The amount of radiation absorbed at any level depends upon the amount of that gas at that level, upon the absorption coefficient of that gas for radiation of that particular wavelength, and also upon the strength of the radiation—and that depends upon how much of the absorbing gas the radiation has already passed through. If the absorption coefficient is small some radiation of this wavelength may reach the ground; but over a wide range of wavelengths including all wavelengths shorter than about 2900 Ångströms (Å) (visible radiation extends from 4000 to 8000 Å), solar radiation is completely absorbed by the atmosphere.

The ozone layer.—When radiation is absorbed by a gas there is, of course, a rise in temperature; but something else may happen. If the radiation is of sufficiently short wavelength some of the molecules of the gas may be broken up into simpler molecules, or even into atoms. This is known as photodissociation. Thus a molecule of water vapour may be split up into a molecule of hydroxyl,

HO, and an atom of hydrogen; a molecule of ozone, O_3 , may be split up into a molecule of oxygen, O_2 , and an atom of oxygen, and so on. While this is happening the results of the dissociation may recombine chemically, either into a molecule of the original gas (in which case there could be a steady state in which the rate of recombination is equal to the rate of dissociation), or perhaps into molecules of a type which would not otherwise be present. The gas ozone is formed in the high atmosphere in just this way; molecular oxygen is dissociated by solar ultra-violet radiation into atomic oxygen, and ozone is then formed chemically from O_2 and atomic oxygen. Ozone itself is dissociated by solar radiation of rather longer wavelength but still in the ultra-violet range. So there are three processes involved: the first results in the formation of atomic oxygen; the second in the formation of ozone; and the third in the destruction of ozone. The quantity of ozone present at any place at any time will depend, among other things, on the relative intensities of these three processes. At levels above 80 km the ozone destruction process is overwhelming and there is no ozone. At levels below 10 km no atomic oxygen is formed (the radiation capable of dissociating molecular oxygen being all absorbed at higher levels) so ozone cannot be formed. Ozone is, however, formed at intermediate levels and so forms a shell over the whole globe. This ozone shell plays a very important part in the affairs of the high atmosphere.

The heat balance.—In order to avoid unnecessary complexity it will be assumed in what follows that ozone is the only atmospheric gas with radiative properties. This, of course, is not so. Ozone is perhaps the most important but in any quantitative analysis other gases would have to be taken into account.

Ozone absorbs solar radiation in a wavelength band extending from 2000 to 3500 Å. Ozone also emits long-wave radiation. The emission of long-wave radiation is continuous, day and night; but the absorption of short-wave radiation occurs only in the day-time. So a diurnal variation of temperature in the ozone layer is to be expected, just as there is a diurnal variation of temperature at the ground. But the temperature variation in the ozone layer is not expected to be large, since in one night the amount of heat lost is sufficient to reduce the temperature only by a few degrees. Rocket soundings are now providing observational evidence of a diurnal variation of about the expected amount.

In high latitudes during the winter the ozone layer is in continual darkness for many months. During this time it is emitting long-wave radiation and, if the temperature were governed only by radiative processes, there would be a continuous fall of temperature in the ozone layer throughout this period. The temperature does, in fact, fall by about 100 degrees K; but even this is far less than suggested by radiative considerations. It must be concluded that heat is transported into the region to balance, in part, the heat lost by radiation. During the summer months the ozone layer in high latitudes is in continuous sunshine, receiving practically twice as much solar radiation as is being received in low latitudes. It would be expected that the temperature would be, in consequence, much higher. The temperature in high latitudes is indeed higher but not nearly as high as radiative processes would suggest. So in summer there must be meridional transport of heat away from the region to balance, in part, the heat gained by radiation.

Meridional transport of heat also occurs in the troposphere, of course. The mechanism for the transport in the troposphere is complex but a good deal is

known about it. Very little is known about the mechanism for heat transport in the high atmosphere, largely because there are so few observations.

The use of ozone as a tracer.—Something may be discovered about circulation systems in the high atmosphere by direct measurement of air movement, but the pressure patterns and the associated wind systems are complex and variable, just as they are at lower levels. It would need large numbers of soundings, from a close network of stations, to sort out just what is happening. However, any air movement which transports heat is likely to change the distribution of such things as water vapour and ozone. Therefore at levels where these gases are stable, i.e. at levels where they are neither created nor destroyed to any appreciable extent, it may be possible to use them as tracers for tracking large-scale air movements. Water vapour concentrations are extremely difficult to measure at high levels, but ozone can be measured. It has been known, from measurements made using ground-based instruments (the Dobson ozone spectrophotometer), that there are features of the 'total ozone' distribution which suggest the existence of some sort of meridional airflow in the ozone region. Firstly, it is found that the measured total ozone is greater in high latitudes than in low (photochemical processes would give the opposite distribution); secondly, it is found that there is an increase in the total ozone in high latitudes in winter. Both these features suggest a polewards movement of air at some level in the ozone region, with subsequent descent and return at some lower level. Measurements of the vertical distribution of ozone would obviously give vastly more information about this circulation, if it exists, than measurement of total ozone, and a good deal of effort is now being put into this in several countries. Ozonesondes have been developed which can be flown on radiosonde balloons and which measure the vertical distribution of ozone at levels up to 30 km or so. Measurements of the vertical distribution can also be made from satellites. Measurements from satellites have the great advantage that they provide world-wide coverage, for long periods, and this is just what is needed for this kind of study.

Techniques of measurement of ozone.—It is not the purpose of this article to say much about techniques of measurement, but it is perhaps appropriate to mention that routine ozonesonde soundings will soon be started at a chain of Meteorological Office stations stretching from Lerwick in the north to Gan on the equator. Also, the satellite ARIEL 2 carries Meteorological Office equipment designed to measure the vertical distribution of ozone. Readers might like to be reminded how, from a satellite orbiting at a height of several hundred kilometres, measurements of ozone concentrations at levels below 80 km can be made. There are a number of possible techniques. The simplest, which is the one used on ARIEL 2, makes the measurements twice per orbit. There is on the satellite a radiation sensor, measuring the intensity of radiation in the wavelength region 2500 to 3500 Å, where ozone has a fairly high absorption coefficient. For most of the orbit the output from this sensor is either zero, when the satellite is in the earth's shadow, or is constant at the 'full sun' value. However twice per orbit, once at sunrise and once at sunset, as the satellite passes into or out of the earth's shadow, the sun is 'seen' through the earth's atmosphere and the radiation will be reduced by ozone absorption (there will be some reduction for other reasons but this can be allowed for). The more ozone there is in the way the greater will be the reduction by ozone absorption.

It takes about 30 seconds for the satellite-sun line to move from just skirting the earth to a position skirting the earth at a distance of 80 km. If the output from the sensor is measured, say every second during the 30-second period, then the vertical distribution of ozone can be computed.

Water vapour.—In the troposphere the mean water vapour mixing ratio decreases more or less steadily with height. There is no obvious change at the tropopause but at a height of about 15 km the mixing ratio seems to become constant. What happens above this? Since there is no obvious source of water vapour in the high atmosphere one would expect the mixing ratio to remain constant with height, up to the level where water vapour is destroyed by photodissociation. However there are American balloon measurements which suggest that the mixing ratio may increase slightly. (Some earlier measurements indicated a large increase of mixing ratio but these measurements are now discounted.) There is some support for this conclusion from measurements made in this country, from aircraft, using radiation techniques.

It used to be thought that the presence of noctilucent clouds, which are observed at high latitudes at heights of 80–85 km, also indicated a high mixing ratio. The cloud particles have now been sampled, by rocket flights from Sweden, and it seems to be confirmed that the particles are coated with ice (and are not simply ‘dust’ particles as some had suspected). If this is so then the air at that level must be saturated. However the temperature at this level in summer is known to be low; the one measurement so far made when noctilucent clouds were present gave a temperature of about 130°K. At this temperature air would be saturated with a mixing ratio no greater than is found at 15 km. More measurements are needed, of course, but clearly the noctilucent cloud argument must be used with caution. Nevertheless it is interesting to note that the supposition that there is no source of water vapour in the high atmosphere may be incorrect. Water vapour may be created by photochemical processes, just as ozone is created. It has been pointed out that methane, which is given off by decaying vegetable matter and by cows and other ruminants, diffuses upwards and is dissociated by ultra-violet light in the high atmosphere. It is possible that quite large amounts of water vapour may be formed as a result of this dissociation. If it can be confirmed that there is a general, even though slight, increase of the mixing ratio with height above 15 km, then the proposition that water vapour is being created in the high atmosphere will be hard to resist.

The mesopause and above.—Whatever the humidity may be at 80 km the fact that there is a temperature minimum there is well established. Below 80 km, between this temperature minimum and the temperature maximum in the middle of the ozone layer, is a region which is known as the mesosphere, and the temperature minimum itself is called the mesopause. It is not difficult to ‘explain’ the existence of the mesopause in a general way: below 80 km there is a rise of temperature because of the absorption of radiation by ozone while above 80 km there is a rise of temperature because of the absorption of radiation by molecular oxygen but what is hard to explain is why the temperature of the mesopause in high latitudes is so much lower in summer than in winter: the difference between summer and winter temperature amounting to as much

as 100°K. The high temperature in winter is almost certainly associated with subsiding air while the low summer temperature may be associated with ascending air; but that is about all that can be said at present.

Above the mesopause there is believed to be a region of steadily increasing temperature—but in this extremely tenuous atmosphere temperature measurements are difficult to make. At 100 km, for example, the air density is less than the density at the ground by a factor of more than 10⁶. At these levels electrical processes, which cannot occur in the denser air at lower levels, become possible. These processes give rise to the ionosphere, to airglow and to aurora—but that is another story.

551.558:551.576.11

UNUSUAL CONVECTION CLOUD

By G. J. JEFFERSON, M.Sc.

The accompanying photograph (see Plate I) was taken at Nicosia, Cyprus at 1530 GMT (1730 local zone time), on 7 June 1964, looking south-eastwards towards the Troodos Mountains. The day had been largely fine but with some cumulus and cumulonimbus development especially over the mountains in the south-west of the island.

At the time of the photograph much of the cloud had flattened out but isolated cumulus heads burst upward from the top of the layer. Their rate of ascent was considerable and, while some of them merely dispersed, a few retained enough of their entity to reach the higher troposphere and form small anvils. The photograph shows one of these, which might be termed ‘anvil puffs’ with enough cloud retained below to indicate the path along which ascent had taken place. Another cumulus head had just started to ascend but its further development was not so striking as the preceding one.

An examination of the ascent for Nicosia radiosonde station for 1200 GMT, 7 June 1964 (Figure 1) shows that the environment air probably had characteristics consistent with development of this kind. The most significant feature is the very high inversion at 660 mb. The layer cloud probably occurred just below this inversion where the air was rather moist.

Temperatures and dew-points at Nicosia for the period 1200–1800 GMT on 7 June 1964 are given in Table I.

TABLE I—TEMPERATURES AND DEW-POINTS AT NICOSIA ON 7 JUNE 1964

Time (GMT)	1200	1300	1400	1500	1600	1700	1800
Dry-bulb temperature °C	31.1	29.8	28.9	26.7	26.6	24.4	23.3
Dew-point temperature °C	12.3	15.8	15.5	16.9	18.0	16.9	15.3

The most interesting feature shown in this table is the steady rise of dew-point between 1200 and 1600 GMT. The 1200 GMT temperature and dew-point would give rise to convection cloud, but probably only up to the inversion at 660 mb. With a rise of dew-point to 16.9°C at 1500 GMT and to 18.0°C at 1600 GMT the possibility of convection breaking through the inversion is quite evident

In fact the 1500 GMT temperature of 26.7°C and dew-point of 16.9°C suggest that ascending air would be able to break through the inversion. Temperatures at places at the same altitude as Nicosia but in the hilly areas, may not have been as high as at Nicosia itself, which is on the open plain at about 720 feet.

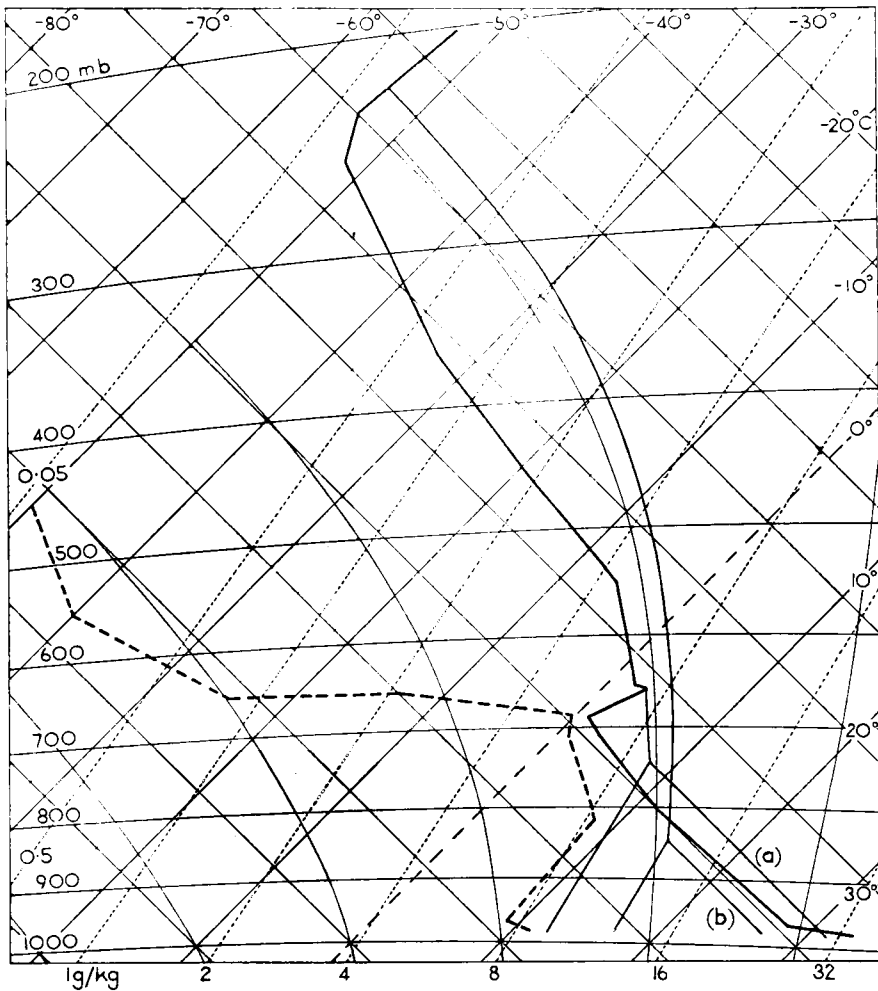


FIGURE 1—NICOSIA ASCENT FOR 1200 GMT, 7 JUNE 1964

— — — Dry-bulb temperatures; - - - dew-point temperatures.
Convection paths are shown for (a) 1200 GMT and (b) 1500 GMT.

However, ascent over the high ground would give an additional impetus to convection. It was clear at the time that the convection was taking place somewhat nearer than the high ground.

The hills which can be seen just to the right of the cloud in Plate I are about 20 miles distant and about 5000 feet high. If we assume the cloud to be 15 miles distant, measurements from the photographic negative allow the heights of the cumulus top and the top of the 'anvil puff' to be calculated. On the photograph these are 12 mm and 32 mm respectively. The focal length of the camera lens was 75 mm. Thus:

$$\text{Height of cumulus top} = 12 \times 15 \times 5280/75 = 12,700 \text{ feet.}$$

$$\text{Height of anvil top} = 32 \times 15 \times 5280/75 = 33,800 \text{ feet.}$$

Both heights would appear to be consistent with the ascent shown in Figure 1 and suggest that the estimated distance of 15 miles was approximately correct.

The large positive energy area above the inversion in Figure 1 can explain the rapid rate of ascent but no explanation can be offered as to how the rising

cloudy air was able to reach such a height without the cloud being dispersed by entrainment of the very dry environment air through which ascent was taking place.

No actual measurements were possible of the time taken for the cumulus head above the inversion (similar to the cumulus head seen in the photograph) to reach the stage of the 'anvil puff' but it is thought that it was between 5 and 10 minutes. If it is assumed to be 10 minutes, then the rate of ascent would be of the order of 2000 feet per minute.

REVIEWS

Rayonnement solaire et échanges radiatifs naturels by Ch. Perrin de Brichambaut. 9½ in × 6¼ in, pp. vi + 304, *illus.*, Gauthier-Villars et Cie, Quai des Grands-Augustins, 55, Paris VI^e, 1963. Price: 46F.

There has been increasing interest in recent years in the measurement of solar and terrestrial radiation. This has been partly as a means to the understanding of the transformation of energy within the system earth-atmosphere and of its variation in time and space, and partly to meet certain needs connected with biological, medical, industrial—including building,—agricultural and hydrological activities. As weather satellites increasingly provide a synoptic picture of radiative flux above the atmosphere, the need becomes more apparent for more observations at the surface. There is no doubt that such radiation observations will eventually be required on a synoptic basis for inclusion in numerical forecasting schemes.

The International Geophysical Year (IGY) instruction manual on Instruments and Measurements of Radiation (1957) gave an account of what was required, but with no diagrams, and during the IGY there were some 400 stations, scattered over the world, measuring global radiation on a horizontal surface, and some 30 stations measuring radiative flux at the surface: most of these stations have continued, but this network is a very open one over land and—apart from the British Ocean Weather Ships and later a Canadian Ocean Weather Ship and isolated observations by research ships—non-existent at sea.

Thus with the recognized need all over the world for an increase in the number of stations measuring solar and terrestrial radiation, it is timely that the present textbook has been issued. Previously much of the information on the subject has been scattered among the original papers, although there is a useful section in the *Handbook of meteorological instruments, Part I*.¹ The book is the fourth volume in a series of monographs of meteorology published under the general editorship of A. Viaut, Director of the Météorologie Nationale. The author is well known in radiation circles; he is a member of the Radiation Commission of the International Association for Meteorology and Atmospheric Physics (IAMAP), and is also a member of the Working Group on Radiation for Regional Association VI (Europe) of the World Meteorological Organization (WMO). His aim, as stated in the introduction, is to produce a practical guide for all those interested in solar radiation in the field of natural energy exchanges. The book has 19 chapters followed by several technical annexes. The first 3 chapters are concerned with the fundamental physical laws of

radiation. Chapter 4 deals with the relevant elements of astronomy, e.g. the declination of the sun at different periods of the year and the meaning of local apparent time. By chapter 5 the account is turning to the different kinds of instruments used, e.g. pyrheliometer for normal incidence, pyranometer (commonly called solarimeter) for radiation received from a hemisphere, normally on a horizontal surface, and to discussion of errors likely in the measurements. Chapter 6 then deals with the recording of the readings from these instruments, including the use of integrating potentiometers. Chapter 7, concerned with the methods of measuring direct solar radiation, is followed by an account, in the next chapter, of the general characteristics of this radiation and of the practical application of the data; the same plan is followed in the successive chapters 9 and 10 which deal with the measurement and interpretation of global and diffuse radiation. After chapters concerned with terrestrial radiation, radiation from natural bodies, radiation from the atmosphere and the general radiation balance, and a chapter describing the usual instruments for the measurement of the duration of sunshine, the last 3 chapters are more general. They discuss the results obtained from the various types of radiation measurements in a climatological manner and biological and psychological effects are mentioned; the last chapter is concerned with the energy utilization of solar radiation, including, under appropriate conditions, the use of solar furnaces, the heating of houses, refrigeration and the conversion of solar energy into electricity, as adopted for power supplies in satellites; mention is made of the architectural applications of the knowledge of solar radiation. The technical annexes are varied, being entitled, atmospheric transparency and visibility, photography, thermo-electric effects, electric circuits for actinometry and data concerning the sun.

Many tables, diagrams and graphs are included, but the diagrams of instruments are not, in general, as detailed as in the *Handbook of meteorological instruments, Part I*; as an attachment at the end of the book there is a series of photographs, albeit rather small, of the various instruments.

A useful account of the subject is thus presented for students generally, and for those coming new to the subject who wish to measure the various elements of solar radiation. Besides the description of instruments, the general background knowledge necessary is mentioned and there are accounts, for example, of the various radiation diagrams, such as Elsasser and Robinson, used for computing radiative flux in the atmosphere, and various aspects of atmospheric scattering (Mie and Rayleigh).

As the author makes it clear, the book is up to date to 1961; thus a relatively new subject like the introduction of modern data logging equipment^{2,3} to eliminate the laborious hand-scaling of charts is not included; there is also no mention of measurements at sea.⁴ It would have been useful, in view of the variety of types of radiation instruments used in different parts of the world, to have mentioned that the Commission for Instruments and Methods of Observations (CIMO) of WMO has organized international comparisons of radiation standards (the first such comparison of solarimeters was at Davos, Switzerland, in 1959) and is continuing to arrange for further such comparisons in future.

It is a pity that the references to literature at the end of the book, stated by the author to be "easily accessible", are so scanty that it would be very difficult for the reader to trace the volumes concerned. For example a reference to

"Robinson—Notes on the Measurement of Atm. Radiation 1947" would eventually lead to a paper in the *Quarterly Journal of the Royal Meteorological Society* for that year with the full title "Notes on the measurement and estimation of atmospheric radiation", but the full reference would have saved the search. The "*Solar Radiation*" by N. Robinson, 1961, must refer to the book, in English, which Professor N. Robinson of Israel hoped to publish about that date, but which is now not due to appear till late 1964. The useful *Handbook of meteorological instruments, Part I* is not mentioned.

The present reviewer joins in the plea of the previous two *Meteorological Magazine* reviewers of volumes^{5,6} in the present series, that an index should be supplied for each volume. This is particularly applicable to the present volume where many instruments, laws and theories, new to the reader, are given the names of those responsible, and, once having read the book, it is difficult to trace a particular name again. Perhaps the general editor of the series would be able to arrange for the missing indexes to be included in a later volume of this most interesting and useful series of books.

L. JACOBS

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Oceanic observations of the Pacific: 1951. 11 in \times 8½ in, pp. xxxviii + 598, *illus.*: *Oceanic observations of the Pacific: 1956*. 11 in \times 8½ in, pp. xlv + 458, *illus.*, Scripps Institute of Oceanography of the University of California. Berkeley and Los Angeles, University of California Press and Cambridge University Press, Bentley House, 200, Euston Road, London N.W.1, 1963. Price: 68s. and 60s. respectively.

These two well-bound volumes of oceanographic data for the Pacific for the years 1951 and 1956 have recently been received. *Oceanic observations of the Pacific* is a medium for publication of oceanographic data collected in the Pacific Ocean and its adjacent seas by co-operating agencies of the United States and Canada.

The publications give maps showing the locations of the observations, the distributions of serial soundings in the Pacific, and the available bathythermograph observations from 1941 onward in the Pacific, Antarctic, and Indian Ocean. It is evident that in spite of this great volume of 'very high quality' information there are vast areas of unobserved seas in the Pacific.

The purpose of the volume is to tabulate results of serial oceanographical soundings to frequently very great depths (at times exceeding 3000 metres). Actual observations are given with interpolated values for every 10 metres to

50 metres, for every 25 metres to 100 metres, for every 50 metres to 300 metres and then every 100, 200 or 500 metres after respectively 300 metres, 800 metres, and 1500 metres. Depths are given in whole metres; sea temperatures are given to two decimal places of °C and salinities are given in parts per 100,000. Oxygen and phosphate contents are also included in the tables. The weather, sea state, the deviation of the sounding wire from the vertical and the slide numbers of any associated bathythermograph 'dips' are included with the tabulations. In some of the soundings interpolated values of temperature and salinity have been used to compute standard parameters. These parameters are functions of water density, specific volume and pressure and they enable water mass and isobaric analysis to be carried out directly on the data without any further processing.

The data tabulated in these volumes are standard and in no way exceptional. Necessary details of the times of the voyages and the ships' names with an outline of non-standard observations are given, but the full story of any specific voyage would need a reference to other books. The publications however provide a full bibliography for such a purpose.

These volumes which are two of a series provide oceanographical data in a very convenient form, typical of those available in an oceanographic data centre.

Meteorologists in the United Kingdom who need this type of information for such problems as the interaction between sea and atmosphere over either a limited sea area or on a world-wide scale should of course apply to the British Oceanographic Centre at present being organized by the British Hydrographic Department, Ministry of Defence (Navy Department). This new centre which is in its infancy and is co-operating with continental and world centres of America and Europe hopes to have the type of information included in these two excellent volumes available on punched cards or tape so that computers can be used with a minimum of preliminary work.

G. A. TUNNELL

Descriptive physical oceanography, by G. L. Pickard, M.A., D.Phil. 5¼ in × 7¾ in, pp. viii + 199, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1964. Price: 25s.

This is a valuable introduction to descriptive oceanography and gives the background of that part of the subject which corresponds in meteorology to air-mass analysis.

It gives the reader the tools for water-mass analysis which is quite as fundamental to oceanography as the concept of air mass is to meteorology. Convective exchanges in the oceans have to take place from the surface downwards and as water is so much more viscous than the atmosphere some of the deep water masses can exist undisturbed for centuries. There are therefore considerable differences on the time scales of fluctuation and exchange in the oceans from those in the atmosphere. Dr. Pickard in this small book has given a very simple account of the methods and materials of analysis, condensed from a huge mass of basic literature. The book is very easy to read and one could get much enjoyment from it on a long journey.

The introductory chapter gives brief notes on the history of oceanography. This includes a discussion of the terms 'synoptic' or 'descriptive' oceanography.

These terms apparently correspond with the 'climatological' sub-division of meteorology. One wonders what the oceanographers will call a truly synoptic oceanographical chart or map.

Chapter 2 gives the physical dimensions and the geological structure of the ocean bottom, which allows the reader to get the oceans into true 'perspective.' The magnitude of the great deeps and the extent of continental shelves are all described. For example the great 11,000 metres of the Marianas Trench is compared with the 8840 metres of Mount Everest. It is stated that the slope of continental shelves is on the average 1 in 500 for an average distance of 65 kilometres increasing to 1 in 20 as they pass to the ocean deeps.

The magnitude of physical and chemical parameters measured instrumentally is given in chapter 3. The magnitudes of density, temperature and salinity are given with some indication of their importance in the analysis of the oceanic circulation. The complex nature of what the oceanographer understands as salinity, its relationship to chlorinity and electrical conductivity are explained with the limitations of the latter in the rapid and accurate measurement of salinity. These techniques require an accuracy of measurement quite beyond that used by meteorologists. It is also pointed out how valuable are other characteristics of the sea like the oxygen content, the colour, and the diffraction of sound waves in investigating the oceanic current circulation at all depths.

Chapter 4 summarizes the results of thousands of observations giving the world-wide distribution of the characteristics of the oceans and their variation with time. For example it is shown diagrammatically that there is on average a maximum of temperature and a minimum of density and salinity at the equator, and salinity maxima in the two tropical zones of the oceans. It is also shown that there is a uniquely rapid increase of density with depth at the equator but a great constancy and uniformity of density below 2000 metres almost everywhere. It is shown that the surface temperatures and salinities are influenced by the weather, ocean currents and the vertical exchanges within the oceans. The oxygen content of the sea is an important tracer element for detecting the age of a water mass but minimum values in the upper 1000 metres in the equatorial Atlantic and eastern Pacific are not yet fully understood.

Chapter 5 shows how conservation principles may be applied to the sea. For example the conservation of salt can be used to analyse the flow in estuaries. Conservation of heat energy can also be applied to the oceans. The greater part of the chapter contains heat budget equations with parameters and measurements familiar to meteorologists. Instruments, physical and chemical measurements and oceanic diagrams are described in chapter 6. The descriptions of instruments are efficient and brief but more diagrams and photographs with some of the associated techniques would have been helpful. The techniques associated with oceanographical diagrams for the study of oceanic circulations are more fully discussed.

Chapter 7 augmented by chapters 8 and 9 is the heart of the book. It is difficult to do justice to them in a review; so much is covered, including the results of much recent work, analysis and thinking that one has to read the chapters with the greatest care to absorb all the details. The very significant role of Arctic water masses and their convergences are explained with the three-dimensional exchanges within the oceans. Included also are brief accounts of sea ice and the oceanic jet stream—the Cromwell current.

The cover of the book is not very durable and started to disintegrate while the book was being read by the reviewer. It would help the reader if references to figures were given with the appropriate page number. A fuller bibliography would be helpful particularly if references to classical works were put at the end of each chapter.

I can recommend this book to mariners and scientists requiring a concise account of modern oceanography, as a preparation for more advanced studies.

G. A. TUNNELL

AWARDS

L. G. Groves Memorial Prizes and Awards

The presentation of the L. G. Groves Memorial Prizes and Awards for 1964 was made by Major K. J. Groves in the Historic Room at the Ministry of Defence, Whitehall, on 6 November 1964. The presentation was presided over by Air Marshal Sir Christopher Hartley and attended by the Director-General of the Meteorological Office, Sir Graham Sutton (See Plate II).

The Memorial Prize for Aircraft Safety was awarded to Flight Lieutenant D. C. Evers, of No. 114 Squadron, RAF Benson, who designed a simple emergency release mechanism for the extractor parachute in transport aircraft which would operate should the extractor or platform mechanism fail during the dropping of heavy supplies. Flight Lieutenant Evers' development should obviate the present procedure whereby a crew member has to sever the parachute cable with bolt croppers in the event of trouble.

The Memorial Prize for Meteorology was presented to Dr. K. H. Stewart, Principal Scientific Officer, of the Meteorological Office, Bracknell, for the most important contribution to the science of meteorology or its application to aviation. Dr. Stewart was in charge of the British team which developed special instruments for the measurement of ozone in the atmosphere, carried in the Anglo-American satellite ARIEL 2, and it is largely due to his imaginative approach to design and his exceptional care and persistence during constant testing and installation in the satellite, that this unique equipment has functioned successfully (see Plate III).

The Air Meteorological Observer's Award went to ex-Flight Sergeant G. F. Earnshaw, formerly with No. 202 Squadron, RAF Aldergrove. He flew 185 sorties in Hastings aircraft during his four and a half years with the Squadron, logging 1900 hours, and his prize was awarded for meritorious work and devotion to duty by a member of aircrew employed on air meteorological observer or other duties relating to meteorology. Flight Sergeant Earnshaw became a Meteorological Observer Leader; he raised the training standards of new 'Met' observers, and was instrumental in improving the efficiency of his section and in perfecting techniques of meteorological survey.

Master Pilot R. E. Purdue received the Second Memorial Award for meritorious work in any field covered by the other prizes. The award is for suggested modifications in the design of aircraft rudder bar and toe brake-assemblies which are likely to eliminate accidents caused by inadvertent braking on

landing. Such accidents, though infrequent, have been suffered by both experienced and inexperienced pilots. Master Pilot Purdue is now on air traffic control duties at RAF Honington.

HONOUR

The Director-General is pleased to announce the award of the Imperial Service Medal to Mr. A. L. Henson, who recently retired after having spent over 40 years in the service of the Crown. He served in the armed forces from the latter part of World War I to 1927, and again throughout World War II. During his Civil Service career, which was devoted entirely to radio communication work, many years were spent on radio direction-finding duties providing navigational and safety services for aviation. For the past few years he has been a Radio Supervisor in the Communications Branch of the Office, working first at Dunstable and later at Bracknell.

OBITUARY

Mr. W. R. Galloway, M.Sc.—The news of the sudden death of Mr. W. R. Galloway, Principal Scientific Officer, at his home in Pinner, Middlesex, on 16 November 1964, at the age of 50, came as a profound shock to his many friends inside and outside the Meteorological Office. Having made a wonderful recovery from a serious heart attack in 1956, he seemed to be enjoying ever-improving health.

Mr. Galloway joined the Meteorological Office in 1937, having been with Dunlop Limited for a short time after leaving University. After attending the Training School, then at Croydon, he served successively at Boscombe Down, St. Athan and Manston before going out to Canada in 1940 as a member of the team of meteorological instructors to R.A.F. pilots and navigators under training in the Dominion. Returning in 1943, he spent only a short time in this country before proceeding to India and he stayed until the end of the war in that theatre.

From 1946 to 1958, Mr. Galloway was wholly employed on civil aviation work, first at Headquarters, then at London Airport and lastly with the Ministry of Aviation Examining Unit. In 1958 he took up an appointment as Chief Meteorological Officer of R.A.F. Flying Training Command, moving on to take charge of the Meteorological Office Training School in 1962. He attended the School on the day of his death.

Wesley Galloway ('Bill' to the many who thought the 'W' stood for 'William') was a proud family man, a loyal and highly respected colleague, and the truest of friends. Of great spiritual strength and integrity, he was incapable of unkind thought, and his charity was boundless. He experienced many personal tragedies, but each seemed only to strengthen his wonderfully philosophic outlook on life.

Wesley Galloway will be sorely missed by a very wide circle of friends. We extend our deepest sympathy to his widow and family.

W.E.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

SCIENTIFIC PAPERS

No. 19—Some further observations from aircraft of temperatures and humidities near stratocumulus cloud, by J. G. Moore, B.Sc.

This analysis of observations made by the Meteorological Research Flight during flights through anticyclonic stratocumulus cloud broadly confirms similar earlier work done by James.

Both sets of results show sharp temperature inversions and hydrolapses above the cloud top with considerable turbulence in the cloud and within the first 300 feet above. The heat balance suggests that heat must be transferred downwards through the cloud top by turbulent diffusion to maintain the heat budget of the cloud and air below. The absence of solar radiation by night requires a greater degree of turbulence by night than by day. It seems probable that in the absence of subsidence near the cloud top, water vapour transferred upwards by turbulent diffusion will remain in the lower part of the inversion layer leading to a gradual upward extension of cloud.

No. 20—The interannual variability of monthly mean air temperatures over the northern hemisphere, by J. M. Craddock, M. A.

Charts are presented based on most of the information readily available, covering most of the northern hemisphere, and showing, for each month of the year, measures of the variability of the mean temperature between one year and another.

THE METEOROLOGICAL MAGAZINE

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REORGANIZATION OF ASSISTANT DIRECTORATES

By the DIRECTOR-GENERAL

As many readers of this Magazine are aware, during the last decade the Meteorological Office has carried out extensive research into mathematical methods of producing forecast pressure and temperature charts for short periods (up to 24 or 48 hours) ahead. Much of this work has been done with the *Ferranti Mercury* computer, known in the Office as METEOR. The effort has been concentrated in the Assistant Directorate for Dynamical Research (Met.O. 11) under the leadership of Mr. E. Knighting, with the Deputy Director of Dynamical Research, (D.D.Met.O.(D)), Mr. J. S. Sawyer, F.R.S. and the Director of Research, Dr. R. C. Sutcliffe, F.R.S., exercising general supervision. During the past two years extensive trials of the method have satisfied us that the mathematically produced prebaratics are, on the average, superior to those constructed by time-honoured 'hand' methods, especially on the 500 mb (about $5\frac{1}{2}$ km above sea level) isobaric surface. At the same time, despite the limitations of the relatively small and slow computer employed, it was demonstrated that such charts could be produced on a routine basis in time to be of use to the Central Forecasting Office.

These considerations have led to a decision to introduce numerical forecasting as routine in the preparation of the daily forecasts. This will take place as soon as possible after the completion of the new COMET computing laboratory in which the *English Electric-Leo* KDF 9 computer will replace METEOR.

The immediate task ahead is to transform what have hitherto been research experiments into daily operations. At the same time advantage will be taken of the greatly enlarged facilities and much higher speed of COMET to extend the boundaries of the forecast area and so, it is expected, to enhance the reliability of the forecasts. The incorporation of objective mathematical methods into what has hitherto been mainly a matter of judgement and experience is perhaps the most radical change in weather forecasting techniques that has occurred in the Office since the introduction of upper air charts.

The creation of a large modern computing laboratory within the Office also means that other objectives can now be studied realistically, such as the automatic editing of the incoming messages. Data processing by high-speed methods is now becoming regular practice in many parts of the Office. Other means of automation, such as chart plotters and line-drawing equipment, are also under development.

To cope with these tasks demands some regrouping and redeployment of staff at Headquarters. The Assistant Directorate for Techniques and Training (Met. O.8) has been relieved of its responsibilities for training and retitled 'Forecasting Techniques'. Under its present Assistant Director, Mr. T. N. S. Harrower, it will in future undertake the development of short-range forecasting techniques, paying special attention to mathematical methods and their adoption for routine use. Met.O.8 will also be responsible for manuals on the operational techniques of forecasting. A.D.Met.O. (FT) will report to the Deputy Director of Central Services, (D.D.Met.O.(C)), Mr. B. C. V. Oddie, and will take over some of the staff from Met.O.11.

Met.O.11 will in future be called 'Forecasting Research', thus reviving an old title. It will revert to basic mathematical research in dynamic meteorology (including, of course, numerical forecasting) and will also be responsible for much of the research in synoptic meteorology hitherto carried out by Met.O.12. This work will come under Mr. Knighting as Assistant Director.

Met.O.12 will assume the title of 'Computing and Data Processing.' Mr. G. A. Bull, who was in charge of Met.O.18 (Support Services) will be in control of the computing laboratory and punched-card system and will also be responsible for the development of data processing and automation generally in the Office. He will report to D.D.Met.O.(C).

Met.O.18 will have the title 'Publications and Training'. Mr. C. J. Boyden, who was in charge of the old Met.O.12 (Synoptic Research) will take control of the State Meteorological Library, the Archives and the Cartographic Drawing Office, and publications of the Office. He will also be responsible for the administration of the Training School and the external training programme. This Assistant Directorate will become part of the Research Directorate under D.D.Met.O.(D).

These changes became effective on 1 December 1964. The construction of the extended computing laboratory and the tests of the new installation are not expected to be completed before the spring of 1965. After this a period must be allowed for the necessary trials of the routine operations, but it is confidently expected that before the end of 1965 the change to more objective methods of short-range forecasting will have taken place and the Office will have entered into a new phase.

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WAVES IN AN INVERSION LAYER

By D. R. GRANT

Introduction.—When flying just below a temperature inversion or in an inversion layer, it is common to find large horizontal variations of temperature. The fluctuations are not usually periodic in nature as far as can be seen by inspection of the temperature records. On 18 October 1963, there was a well-marked inversion at a height of about 6500 feet (800 mb) over southern England and an anticyclone to the south was centred over France. On a flight on that day large-amplitude temperature fluctuations were measured which clearly contained a periodic component. Some details of the records are given in this article.

Flight procedure.—Two aircraft of the Meteorological Research Flight equipped with fast-responding instruments made ascents and descents in clear

air through the inversion in directions approximately up and down wind. The aircraft were separated in the vertical by 700, 400 or 200 feet, and as nearly as possible one above the other. Some horizontal runs were also made with a vertical separation of about 100 feet. All the measurements were made just to the west of Farnborough, Hampshire, between 1100 and 1230 GMT.

Results.—A temperature sounding made at the start of the flight is shown in Figure 1. Subsequent soundings showed a similar temperature structure, but the height of the base of the inversion varied over a range of about 500 feet. The height of the horizontal flight discussed later is marked on Figure 1, but this is not necessarily the correct height relative to the inversion base. On all soundings, however, the temperature at this level was increasing with height.

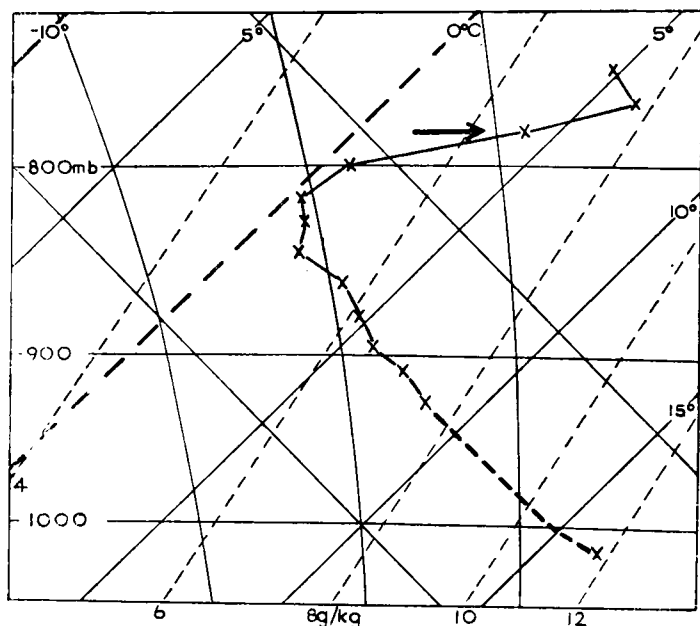


FIGURE 1—TEMPERATURE SOUNDING AT FARNBOROUGH ON 18 OCTOBER 1963

The bold arrow marks the height of level flight.

The pecked line shows where the curve had to be estimated as no temperature readings were available.

The initial ascent and descent showed nothing unusual in the way of temperature fluctuations. Later, however, large fluctuations of temperature were experienced by both aircraft between heights of 6500 and 7000 feet. At this time the aircraft were descending at 500 ft/min separated in the vertical by about 200 feet. Only over a very shallow layer (about 200 feet) was there any correlation between the fluctuations of temperature measured by the two aircraft at the same time. The fluctuations obtained while the aircraft were changing height were wave-like oscillations but they did not extend over one complete wavelength.

When, a little later, the aircraft were flying horizontally with a height separation of about 100 feet and within the inversion layer (i.e. when the temperature was increasing with height), there was a clear correlation between the records, although the amplitude of the fluctuations differed considerably. An example of the temperature records obtained at this time is given in Figure 2.

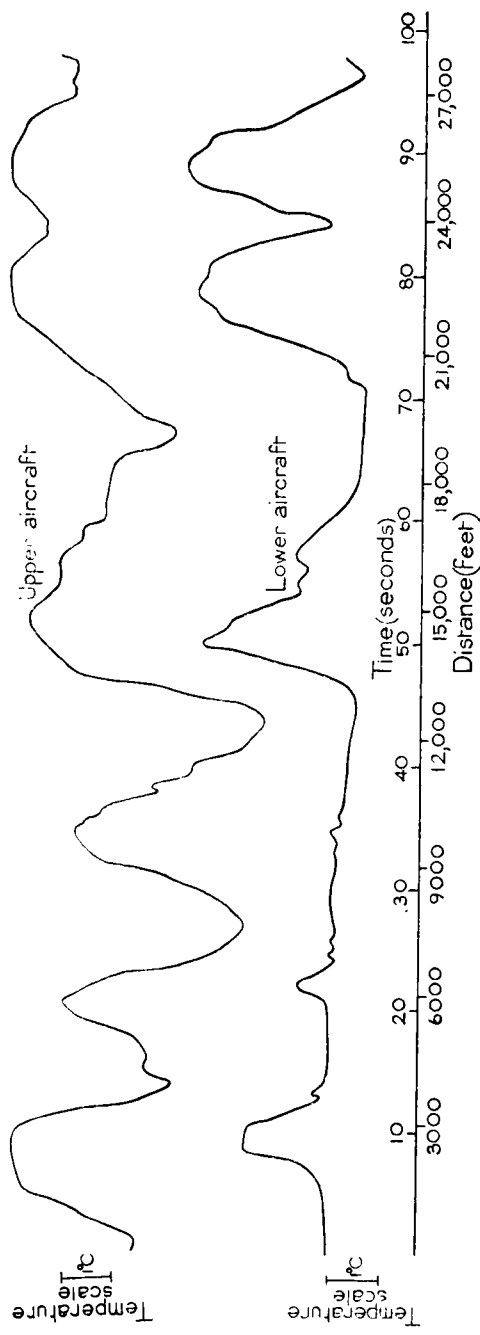


FIGURE 2—SIMULTANEOUS TEMPERATURE RECORDS OBTAINED FROM TWO AIRCRAFT SEPARATED IN THE VERTICAL BY 100 FEET ON 18 OCTOBER 1963

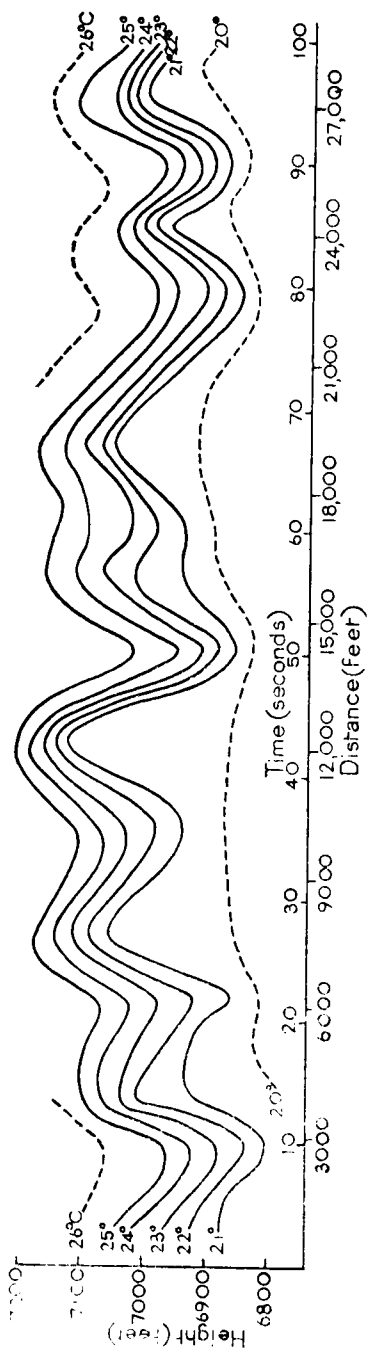


FIGURE 3—VERTICAL CROSS-SECTION OF POTENTIAL TEMPERATURE IN AN INVERSION LAYER ON 18 OCTOBER 1963

At 7500 feet potential temperature was 28°C and at 6500 feet it was 15°C, with no wave-like fluctuations at either level. The lower, surface layer was near isentropic with potential temperature 15°C.

The periodic nature of the fluctuations and the correlation between the two levels is clearly seen. Simultaneous measurements of humidity showed that the warm air was drier than the cold air. Figure 3 shows a vertical cross-section of potential temperature obtained from the same records as Figure 2. This shows that the maximum crest-to-trough amplitude of the waves in the isentropic surfaces was about 150 feet and the wavelength was about 4000 feet.

When the aircraft were flying at a constant height, the periodic temperature fluctuations were not experienced continuously. It was quite common for the temperature record to become fairly steady for long periods. There are two possible reasons for this. Either the waves were not present at all at certain places or the level at which they were present fluctuated from place to place. The former reason would explain the absence of temperature fluctuations on the early ascents and descents, but the observed variation in the height of the base of the inversion would lead one to expect a variation in the level of the waves from place to place. It is quite possible that both explanations are correct.

Conclusions.—The observations show wave-like variations in the height of the isentropic surfaces in an inversion layer. The waves were confined to a layer about 500 feet thick, their crest-to-trough amplitude being 150 feet and their wavelength being 4000 feet.

Additional note by J. S. Sawyer.—

Comparison with theory of gravity waves.—It is interesting to compute the frequency and velocity of the waves observed on 18 October 1963 if they are interpreted as 'short' internal gravity waves on a simple density discontinuity. In such wave motion it is assumed that the fluid boundaries are sufficiently far distant from the discontinuity not to interfere with the motion and the frequency equation is

$$\nu = \left(\frac{\pi g \Delta \theta}{\lambda \theta} \right)^{\frac{1}{2}}$$

(derived from the equation (Lamb¹) for the velocity of propagation) where ν is the frequency, g the acceleration due to gravity, θ the potential temperature, $\Delta \theta$ the total change of potential temperature from the lower near-isentropic layer to above the inversion, and λ the wavelength. Taking $\lambda = 4000$ feet, $\Delta \theta = 13^\circ\text{K}$, and $\theta = 296^\circ\text{K}$ we obtain $\nu = 3.33 \times 10^{-2}/\text{second}$. This gives a period $\tau = 2\pi/\nu = 189$ seconds and velocity $= \lambda/\tau = 6.9$ metres/second.

The wavelength may have been overestimated because the aircraft was not necessarily flying perpendicular to the wave fronts and this would lead to an underestimate of the calculated velocity. The wind speed at the inversion level was around 8 m/s, so it is possible that the observed waves were stationary orographic lee-waves. However, it is also possible that the waves were not stationary and were initiated by convection below the inversion as in the experiments reported by Townsend.² In view of the light surface winds and absence of high hills round Farnborough this is perhaps the more likely explanation.

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SOME ASPECTS OF THE CLIMATE OF SOUTH-WEST ASIA

By A. V. DODD

U.S. Army Natick Laboratories

South-west Asia provides a challenge to the climatologist because of the general lack of meteorological observations in the interior areas of the region; areas which may be as hot as any in the world. In the interior of Arabia, meteorological observations have recently been made in conjunction with oil exploration and some of the climatic blanks are now being filled.

January and July maps of mean and extreme temperature and mean precipitation in south-west Asia, revised in the light of the new data, are presented in this report along with more specific data for the Rub al Khali or 'Empty Quarter' of Saudi Arabia. The maps are estimates of the average and extreme patterns of occurrence. They should be revised when more complete meteorological records are available.

South-west Asia can be delimited on the map by the five bordering seas: the Mediterranean, the Red, the Arabian, the Caspian, and the Black. The influence of the seas, however, is restricted by the prevailing pressure patterns and the restraining influence of mountains so that aridity and continentality characterize most of the area (see Figure 1).

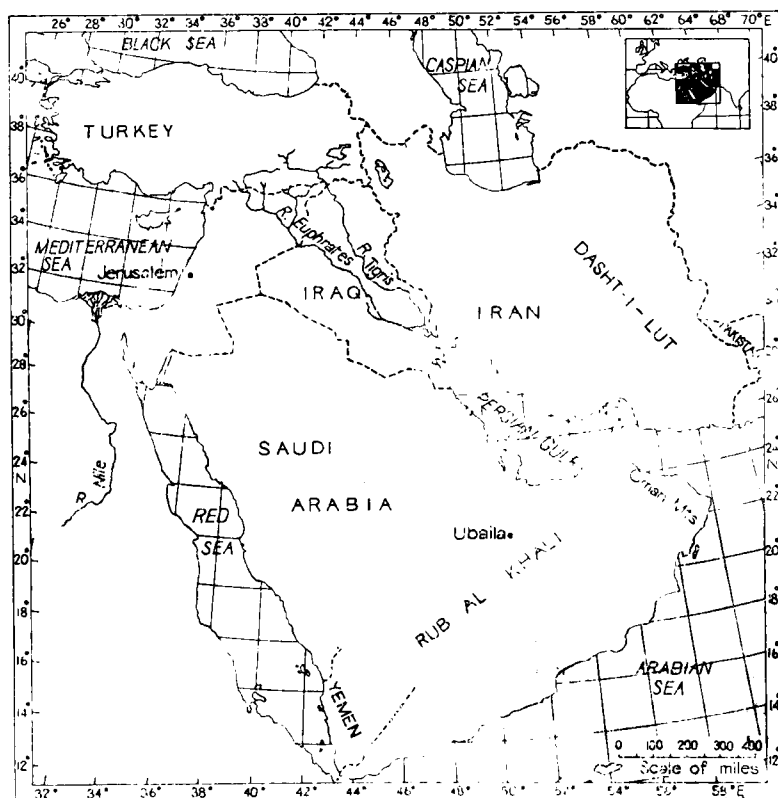


FIGURE 1—MAP OF THE AREA

Winter climate.—In winter a belt of high pressure lies to the north and north-east of south-west Asia over Mongolia and Siberia. Outflowing air from

this high dominates the circulation of all south-west Asia except the southern coast of Iran and the southern portion of the Arabian peninsula. Temporary weakening of this high pressure permits modified polar maritime air from the North Atlantic Ocean to invade the area in migrating storms which generally follow the low-pressure track associated with the comparatively warm waters of the Mediterranean Sea. These storms are the major source of precipitation in much of south-west Asia.

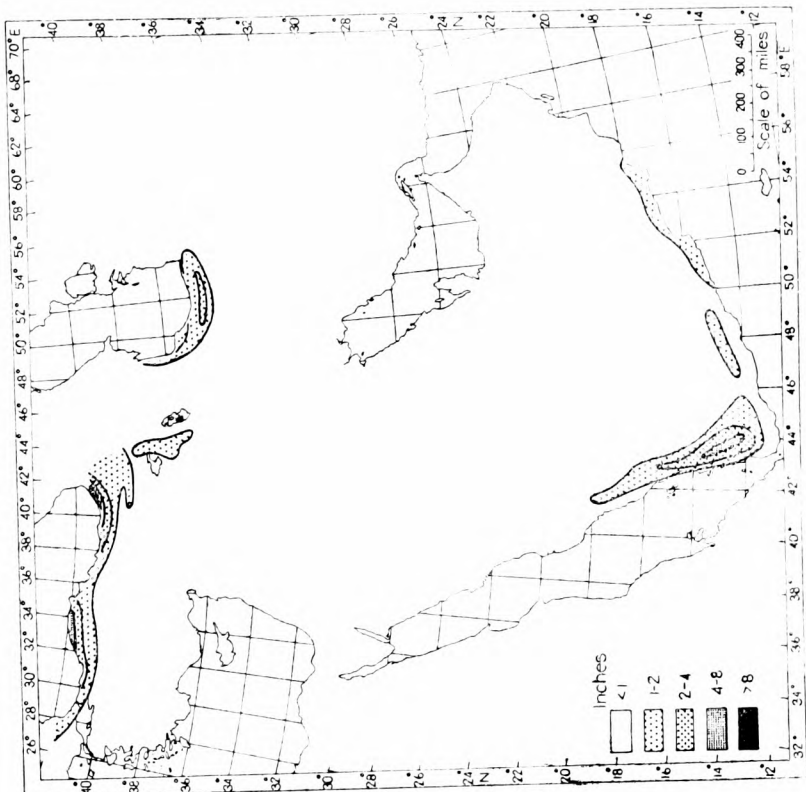
Although winter is the season of maximum precipitation in most of the region, precipitation is plentiful only near the coasts of the three northern seas and on the exposed slopes of the mountains in Turkey and Iran (Figure 2(a)). Near the Mediterranean, snow is uncommon at sea level. Farther north and at higher elevations snowfall may be heavy. In the mountains of eastern Turkey high passes are clear of snow only during summer, and even at Jerusalem (2485 feet above MSL) snow depths of three feet have occurred. South of 28°N rainfall is light and snowfall is unusual, although snow occasionally occurs in the southern highlands of Iran and in the mountains of Oman. Heavy snowfalls have been reported at high elevations in Yemen.

Even in winter, part of the south Arabian desert has experienced temperatures above 100°F (Figure 3) and afternoon temperatures are generally above 70°F at elevations below 2000 feet. As far north as the Caspian and Mediterranean littoral, temperatures as high as 80°F occur in January as warm air from the south is drawn into the migratory lows. (In spring and autumn maximum temperatures of above 100°F along the Mediterranean are associated with this same southerly flow of air.) The contrast in air mass as the front passes and cooler maritime air sets in is notable. In Turkey absolute maximum temperatures in January range from near 50°F in the high mountains of the north-east to above 70°F on the Mediterranean and Black Sea coasts. The January mean daily maximum follows a similar pattern with below-freezing averages in the mountains of the east to averages above 50°F on the Mediterranean coast (Figure 4).

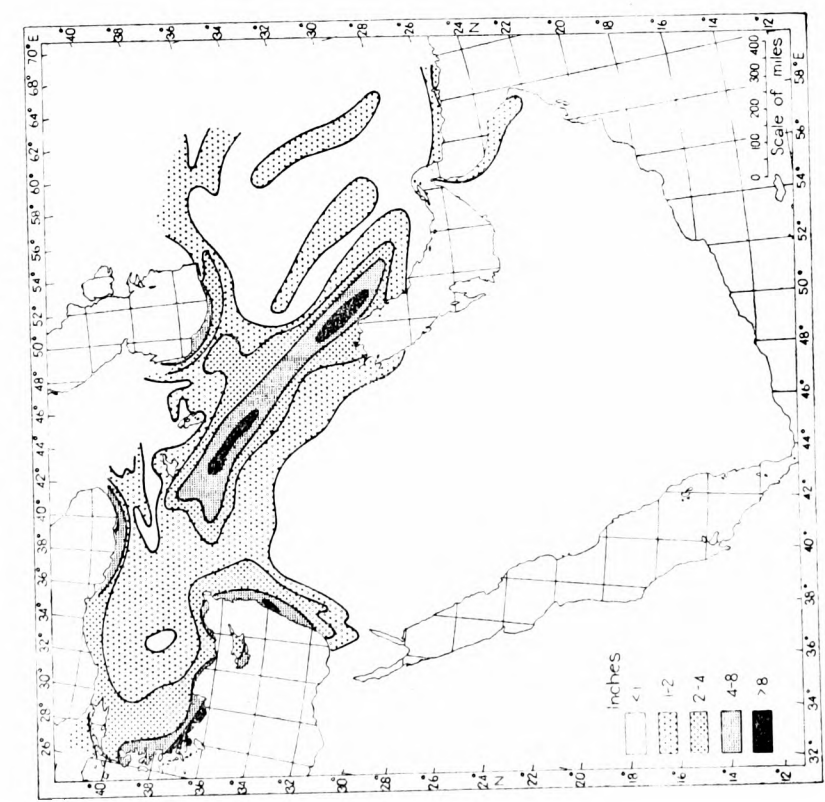
Absolute minimum temperatures in January range from above 60°F at Aden in the extreme south to below -30°F in the mountains of north-eastern Turkey (Figure 5). Similarly, January mean daily minimum temperatures, representative of early morning conditions, range from above 70°F on the Arabian Sea coast to below zero in eastern Turkey and north-western Iran (Figure 6). Frosts have never occurred along the southern coasts and are rare in south-east Arabia.

Summer climate.—In summer the circulation over south-west Asia is controlled by a thermal low centred over north-west India and Pakistan. Low pressure also undoubtedly exists over the interior of Arabia to complicate the circulation over that large land mass. The combination of this low complex with the Azores high to the west results in the transport of dry continental air from the north into the region. Only in the extreme north and in southern Arabia is this pattern broken. In the bulk of the area cloudless skies allow the maximum radiation, and extremely high temperatures result.

Summer precipitation is restricted to southern Arabia, particularly Yemen in the south, and to the border lands of the Black and Caspian Seas in the



(a) January



(b) July

FIGURE 2—MEAN PRECIPITATION

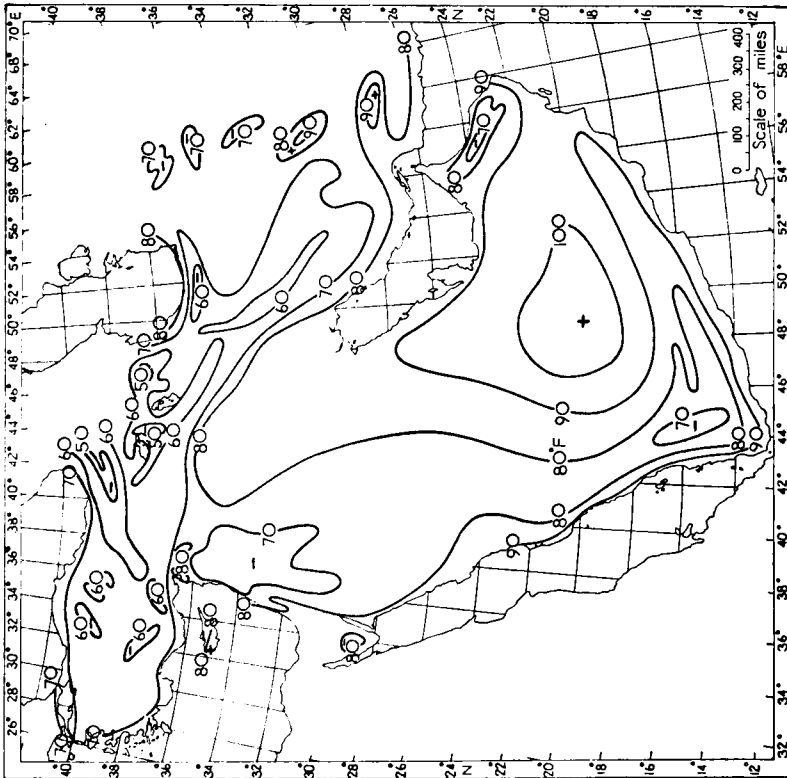


FIGURE 3—JANUARY ABSOLUTE MAXIMUM TEMPERATURE

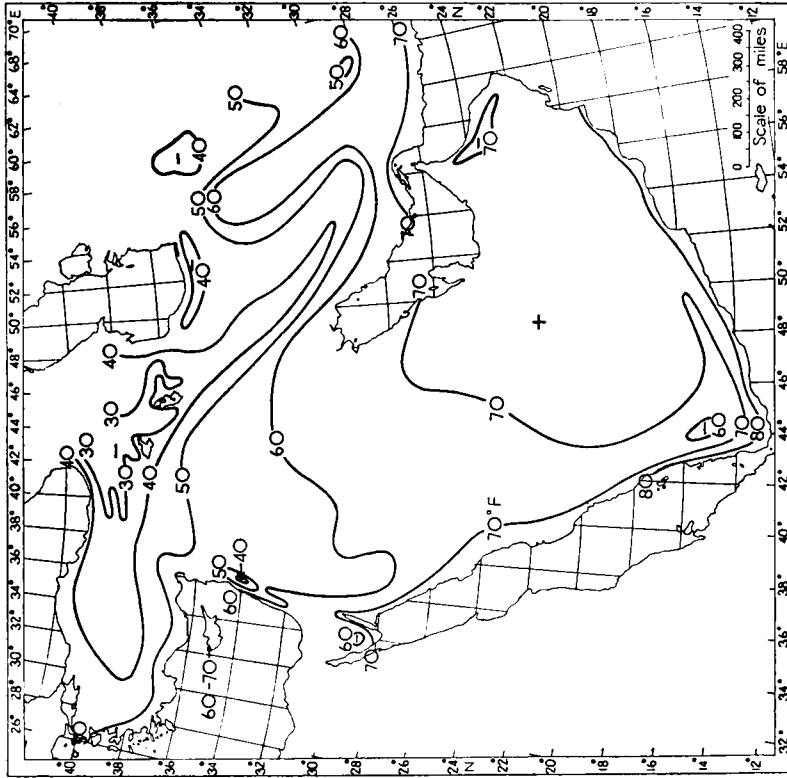


FIGURE 4—JANUARY MEAN DAILY MAXIMUM TEMPERATURE

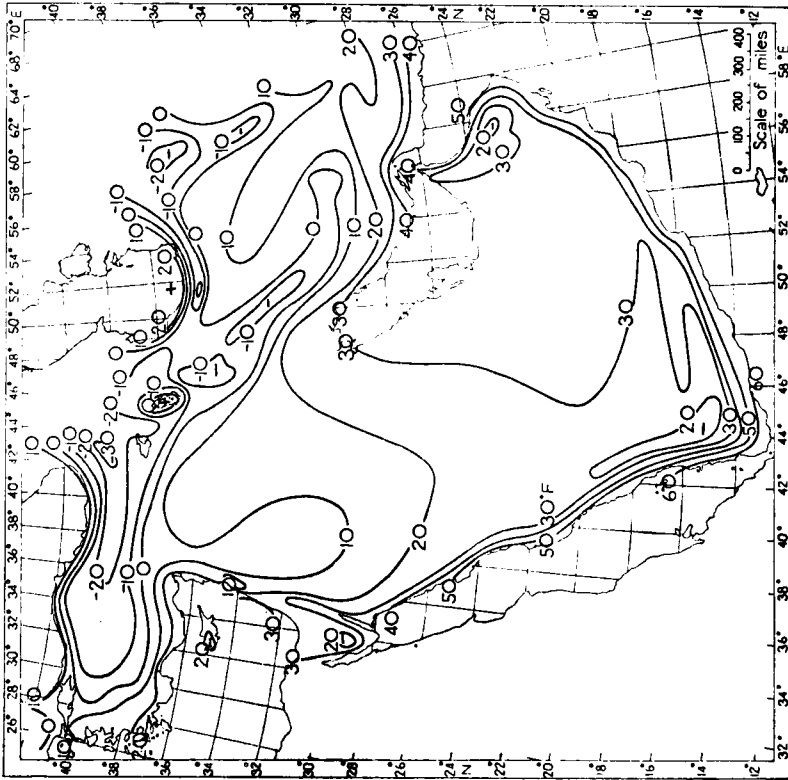


FIGURE 5—JANUARY ABSOLUTE MINIMUM TEMPERATURE

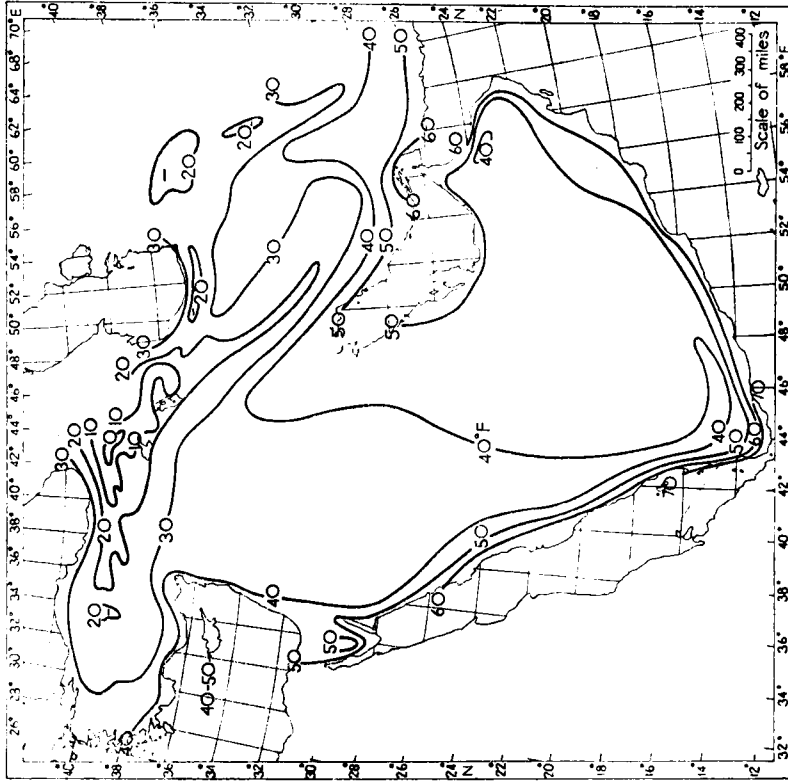


FIGURE 6—JANUARY MEAN DAILY MINIMUM TEMPERATURE

north (Figure 2(b)). Some precipitation can be expected each July along the Mediterranean coast near the border of Turkey and Syria, and in the mountains of Iran and Turkey. However in the bulk of south-west Asia any summer may be entirely rainless and in the interior of Iran some stations have never reported rain in June, July, or August.

The most pleasant summer weather in south-west Asia is experienced in the highlands of Yemen where radiation is reduced by clouds associated with the south-west monsoon, and temperatures are moderated by the higher elevations. Rainfall is ample for local farming and for underground supply of water to favoured locations in the Arabian desert.

The distribution of absolute maximum temperatures in south-west Asia is shown in Figure 7. Observations at drilling sites of the Arabian-American Oil Company show that a large part of the interior of Saudi Arabia has absolute maximum temperatures above 120°F, and it is expected that if longer records were available, temperatures above 130°F would have been recorded in the interior of the Arabian desert. Although confirming records are not available, it is likely that the Dasht-i-Lut, a large basin in south-western Iran, is almost as hot. Temperatures above 120°F have also been observed in the Tigris-Euphrates Valley and inland from the Persian Gulf in Iran. The areas of south-west Asia which have not experienced temperatures above 100°F in July are limited to the higher mountains in the north, and to mountains and part of the coastal strip in the south.

Mean daily maximum temperatures are above 110°F in a vast area extending from southern Arabia 1300 miles to northern Iraq and then in a narrow band through southern Iran (Figure 8). The Dasht-i-Lut also has extremely high temperatures. The highest mean temperature in Iran, 106°F in July, was reported from Shahdad on the edge of this basin. The occurrence of mean daily minimum temperatures above 80°F in the Dasht-i-Lut, in much of southern Arabia, and on the littoral of the Persian Gulf and Red Sea further illustrate the torrid summer conditions in south-west Asia (Figure 9). Some stations on the immediate coasts of the Red Sea and Persian Gulf have no record of July temperatures below 70°F (Figure 10).

The largest hot area of south-west Asia is the virtually unpopulated Rub al Khali, an area in south-east Arabia of some 400,000 square miles covered mainly by sand dunes. The extreme heat experienced in the Rub al Khali is illustrated by the temperature trace during a 10-day period at Ubaila (Figure 11). On only one day did the temperature fail to reach 120°F during this period and on 23 July 1954 the minimum temperature for the day was 100°F. Not only was it hot, but at times it was humid. Although afternoon relative humidities were deceptively low, usually below 20 per cent, they often indicated high absolute humidities. The highest dew-point during the 10-day period was 79°F at 0600 local time on 25 July. Later in the summer dew-points above 80°F were observed. When high temperatures are accompanied by high humidities intolerable conditions occur. It is easy to understand the translation of Rub al Khali—abode of emptiness.

A clue to the source of high humidity lies in the fact that rain fell twice during the 10-day period illustrated. It is felt that Ubaila is near the northern

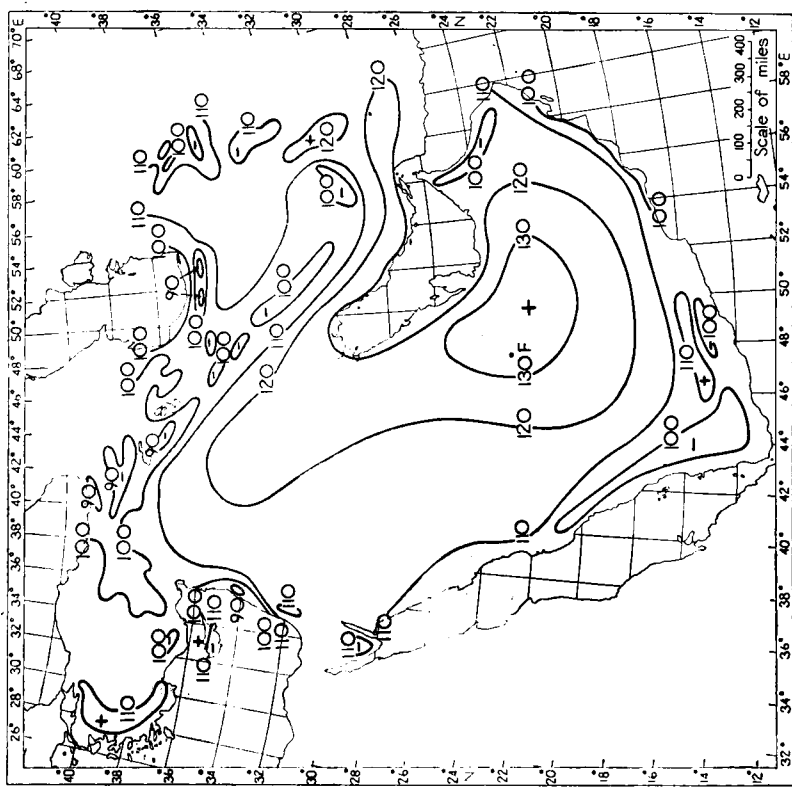


FIGURE 7—JULY ABSOLUTE MAXIMUM TEMPERATURE

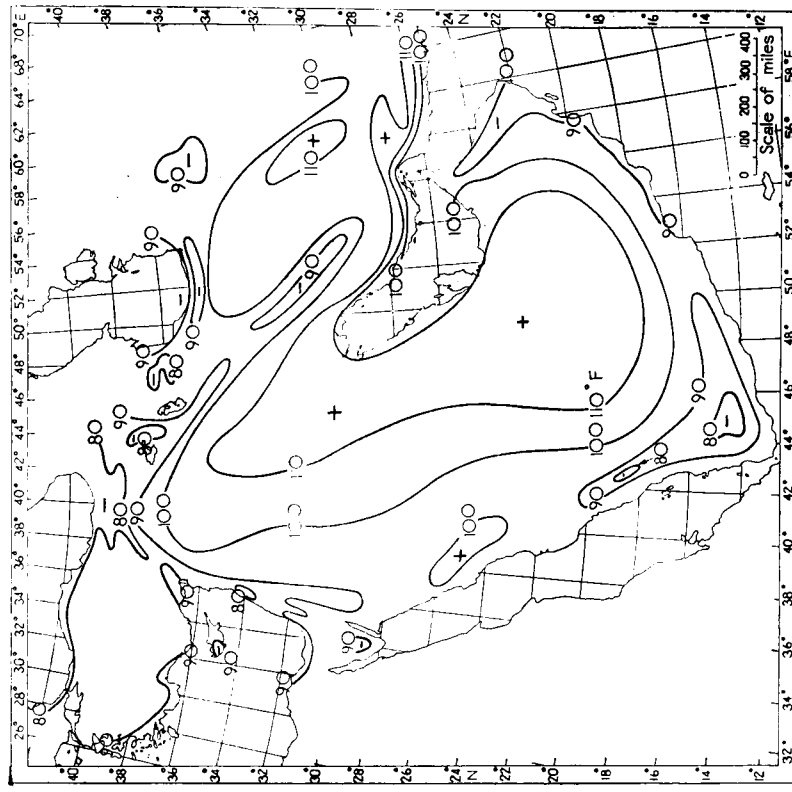


FIGURE 8—JULY MEAN DAILY MAXIMUM TEMPERATURE

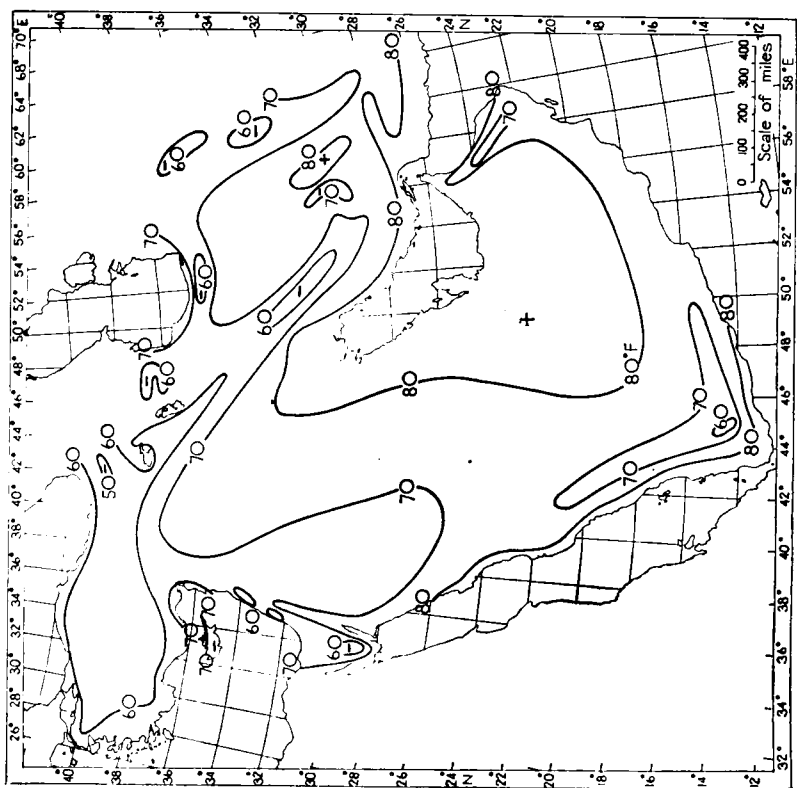


FIGURE 9—JULY MEAN DAILY MINIMUM TEMPERATURE

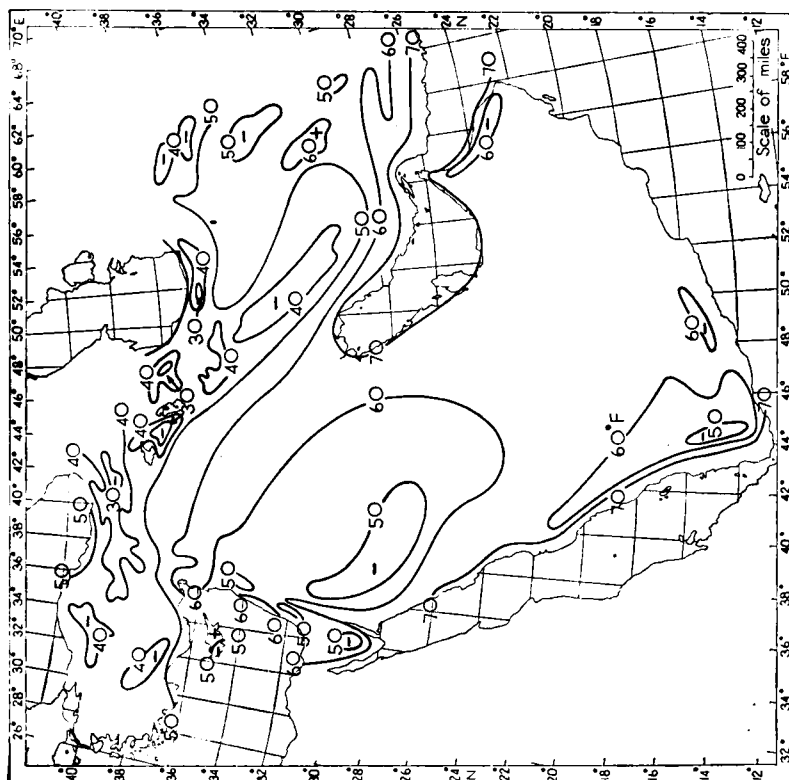


FIGURE 10—JULY ABSOLUTE MINIMUM TEMPERATURE

TEMPERATURE AND RELATIVE HUMIDITY AT UBAILA, SAUDI ARABIA DURING A TEN DAY PERIOD IN JULY 1954

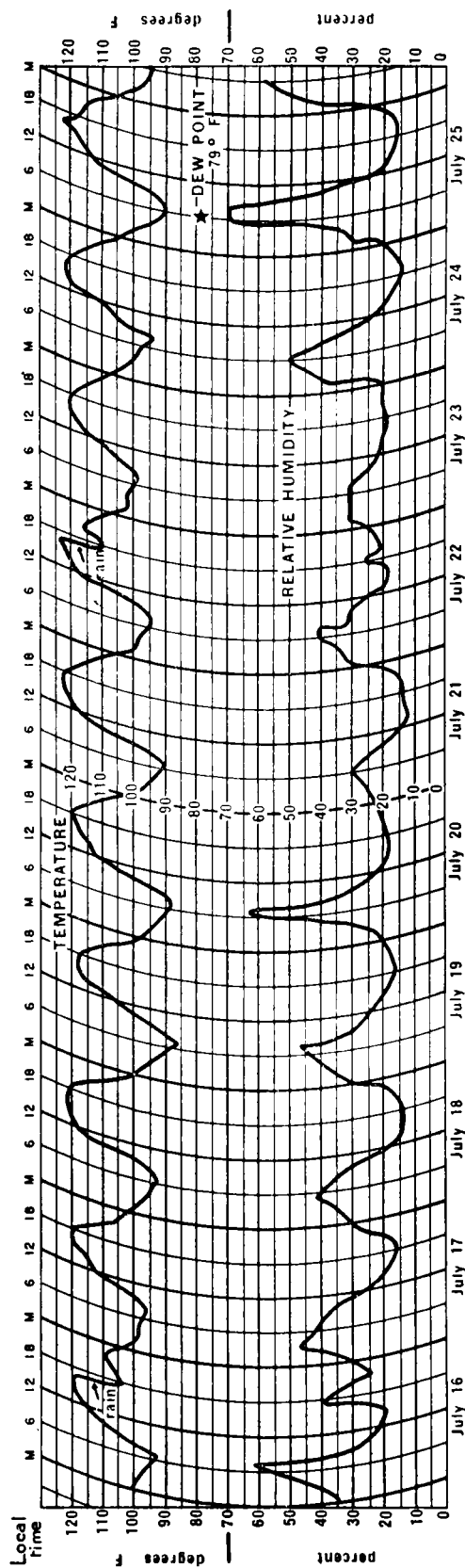


FIGURE 11—TEMPERATURE AND RELATIVE HUMIDITY TRACES AT UBAILA

limit of penetration of the south-west monsoon and therefore is subjected to the convective showers that are associated with the influx of moist air from the Arabian Sea.

Acknowledgements.—The efforts of a number of people are involved directly or indirectly in the preparation of this report. The climatic maps were generalized from maps prepared by climatologists of Earth Sciences Division, United States Army Natick Laboratories, Natick, Massachusetts and were drawn by A. Greenwald. Much of the data for Arabia, including the hygrothermograph traces for Ubaila, were obtained from the Arabian-American Oil Company by the Air Weather Service, USAF.

A special word of appreciation is due to the personnel, unknown to the author, who are responsible for the observations at Ubaila.

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DISTRIBUTION OF CROPS WITH RESPECT TO MEAN POTENTIAL SOIL MOISTURE DEFICIT AT THE END OF AUGUST

By JUDITH M. WALKER

Introduction.—It is a well-established fact that plants need moisture to live, and that some plants need more than others. In view of this fact, it was decided to do a survey of crop distribution in England and Wales to find out if the soil moisture deficit at the end of August is related to the percentage ratios between the areas allocated to certain crops as compared with areas for other crops, i.e. whether a particular pattern of farming is related to availability of moisture.

Method of analysis.—The counties were grouped into the regions shown in Table I. The county rainfall averages are taken from tables of averages for the period 1916–50¹ and estimated potential transpiration averages for April to August were extracted from tables of monthly averages for the period 1930–49². By subtracting rainfall from transpiration, a value was obtained for each county of mean potential soil moisture deficit at the end of August. By suitable weightings by areas, values of the deficit were also obtained for the regions.

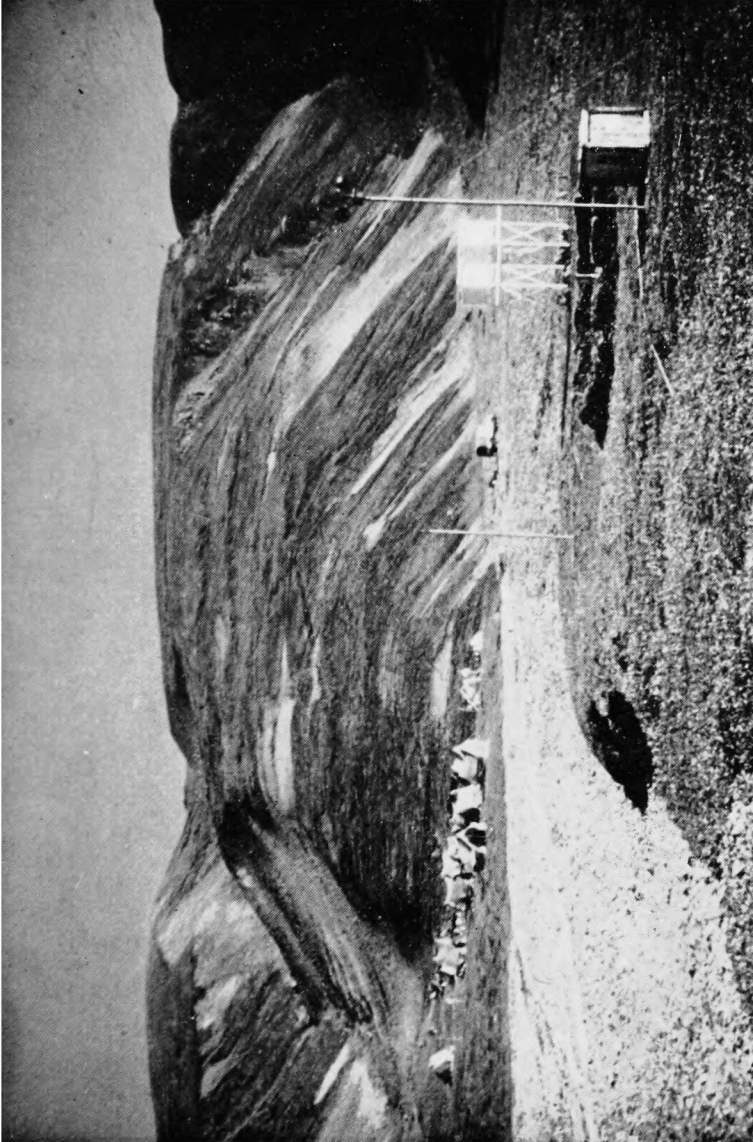
The following data were extracted from *Agricultural Statistics*³ for each county in 1960.

Total farm acreage (crops, grass and rough grazing); crops and grass acreage; grass acreage; rough grazing acreage; lucerne acreage; corn acreage (wheat, barley and oats); wheat and barley acreage; oats acreage; corn and orchard acreage. The following percentage ratios were then obtained for each county and for each region:

- | | |
|---|---|
| (a) Lucerne to grass | (e) Corn and orchard to crops and grass |
| (b) Grass to crops and grass | (f) Wheat and barley to corn |
| (c) Rough grazing to total farm | (g) Oats to corn |
| (d) Grass and rough grazing to total farm | |

TABLE I—MEAN POTENTIAL SOIL MOISTURE DEFICIT FOR ALL COUNTIES OF ENGLAND AND WALES AND PERCENTAGE RATIOS OF CROPS IN 1960

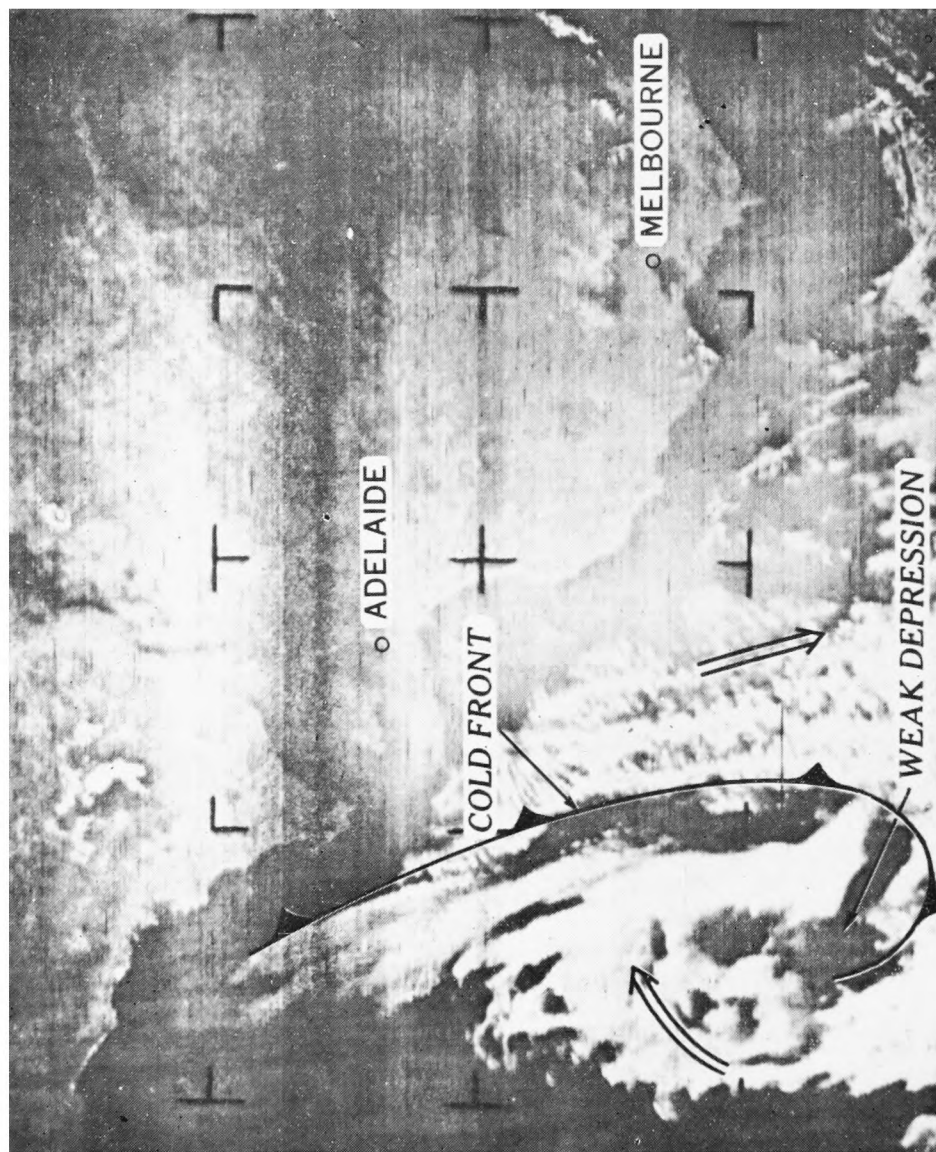
	Mean potential soil moisture deficit (inches)	Col. (a)	Col. (b)	Col. (c)	Col. (d)	Col. (e)	Col. (f)	Col. (g)
			<i>percentage ratios</i>					
(A) NORTH-EAST	—0.30	0.02	73	37	83	19	61	42
Durham	0.00	0.02	65	24	74	26	36	42
Northumberland	—0.60	0.02	77	44	87	15	67	43
(B) NORTH-WEST	—3.93	0.02	83	37	89	11	35	61
Cumberland	—5.05	0.04	85	41	91	9	9	84
Lancashire	—1.50	0.01	78	22	83	14	51	47
Westmorland	—8.45	0.00	93	54	97	5	13	81
(C) YORKSHIRE	1.34	0.10	58	25	68	30	80	22
East Riding	3.30	0.18	41	2	42	44	83	16
North Riding	0.70	0.10	63	33	75	27	83	27
West Riding	—1.20	0.07	66	28	75	23	73	25
(D) NORTH-EAST MIDLANDS	4.11	0.66	43	6	48	37	85	13
Derbyshire	0.25	0.10	79	21	83	16	56	37
Lincolnshire: Kesteven	5.55	1.88	34	1	34	46	91	9
Lincolnshire: Lindsey	4.40	0.45	37	1	37	43	88	11
Lincolnshire: Holland	5.15	0.12	15	1	17	35	91	8
Nottinghamshire	4.05	1.18	47	1	47	40	81	18
(E) CENTRAL MIDLANDS	3.71	0.42	64	1	65	29	79	19
Leicestershire	3.35	0.21	69	1	69	25	70	27
Northamptonshire	4.35	0.71	61	1	61	31	85	14
Rutland	3.95	0.38	54	1	54	35	89	10
Warwickshire	3.30	0.35	65	1	65	28	76	20
(F) WEST MIDLANDS	2.72	0.17	73	5	75	19	68	23
Cheshire	2.05	0.06	78	7	72	15	48	37
Herefordshire	3.35	0.12	71	4	72	20	72	25
Shropshire	3.00	0.16	72	6	74	20	71	17
Staffordshire	1.70	0.16	77	4	77	17	71	19
Worcestershire	3.90	0.46	65	3	66	24	76	21
(G) SOUTH-EAST MIDLANDS	5.31	2.42	28	1	29	49	91	8
Bedfordshire	5.00	1.32	34	1	34	44	91	8
Cambridgeshire	5.80	3.40	19	1	20	52	92	7
Hertfordshire	4.70	2.69	42	2	43	47	89	11
Huntingdonshire	5.30	1.63	27	1	28	49	93	7
(H) EAST ANGLIA	5.59	4.29	27	3	29	50	91	8
Essex	6.15	3.09	31	3	33	50	92	8
Norfolk	5.20	4.61	26	4	29	47	91	8
Suffolk	5.60	5.20	26	3	28	54	90	8
(J) SOUTH-EAST	5.45	0.89	57	5	59	31	81	18
Kent	6.25	1.40	47	3	49	37	83	16
Middlesex	5.85	0.07	59	8	61	23	82	17
Surrey	5.60	0.95	65	4	66	24	79	19
Sussex	4.50	0.49	66	6	68	26	79	19
(K) SOUTH MIDLANDS	3.79	1.07	63	3	64	30	87	11
Berkshire	4.45	2.56	52	4	54	39	90	9
Buckinghamshire	4.50	0.76	69	2	69	26	83	15
Gloucestershire	2.55	0.45	70	4	72	24	87	11
Oxfordshire	4.45	1.76	57	2	57	37	88	11
(L) SOUTH	3.84	0.69	64	12	68	28	90	9
Dorset	4.00	0.30	76	8	78	18	87	11
Hampshire	4.50	0.94	53	15	60	36	90	9
Isle of Wight	4.90	0.59	66	12	69	23	84	14
Wiltshire	3.00	0.55	66	10	69	28	91	8
(M) SOUTH-WEST	0.68	0.14	79	16	82	14	65	15
Cornwall	0.40	0.09	75	13	78	17	57	9
Devonshire	0.35	0.13	78	21	83	15	66	19
Somerset	1.60	0.21	83	8	85	11	79	18
(N) NORTH WALES	—2.18	0.08	86	36	91	9	24	56
Anglesey	1.65	0.05	87	13	88	9	30	61
Gaernarvonshire	—10.00	0.09	88	60	95	9	13	61
Denbighshire	0.20	0.08	86	35	91	10	20	57
Flintshire	3.30	0.13	85	10	94	11	37	45
(P) CENTRAL WALES	—5.29	0.06	86	51	93	9	17	67
Brecknockshire	—5.30	0.05	86	62	95	7	17	81
Cardiganshire	—3.75	0.10	82	39	89	12	11	66
Merioneth	—10.30	0.06	91	72	98	5	2	79
Montgomeryshire	—4.75	0.07	88	42	93	9	29	52
Radnorshire	—1.30	0.06	85	43	91	8	15	81



Photograph by G. Yates

PLATE I—SITE OF THE BASE CAMP AT STATION B IN ICELAND DURING THE BRITISH
SCHOOLS EXPLORING SOCIETY'S EXPEDITION IN 1960

See page 52.



Photograph by the Australian News and Information Bureau

PLATE II—PHOTOGRAPH TAKEN BY NIMBUS A AT MIDDAY ON 14 SEPTEMBER 1964,
AS THE SATELLITE SPED NORTHWARDS OVER THE SOUTHERN OCEAN AND SOUTH-
EASTERN AUSTRALIA

(See page 62).



Photograph by the Australian News and Information Bureau

**PLATE III—THE AUTOMATIC PICTURE TRANSMISSION UNIT AT THE ROYAL AUSTRALIAN
AIR FORCE BASE AT LAVERTON, NEAR MELBOURNE**

The antenna tracks the satellite, picks up its signals and relays them to the Bureau of Meteorology's central analysis office in Melbourne (see page 62).

To face p.49



Photograph by R. K. Pilsbury

PLATE IV—CIRRUS CLOUD ASSOCIATED WITH A JET STREAM OVER SOUTHERN
ENGLAND ON 22 JUNE 1963

The photograph was taken at Bracknell at about 1600 GMT with the camera facing towards the north-east, and the cloud can be compared with that in Plates III and IV in the *Meteorological Magazine* of March 1964.

TABLE I—MEAN POTENTIAL SOIL MOISTURE DEFICIT FOR ALL COUNTIES OF ENGLAND AND WALES AND PERCENTAGE RATIOS OF CROPS IN 1960—*contd.*

	Mean potential soil moisture deficit (inches)	Col. (a)	Col. (b)	Col. (c)	Col. (d)	Col. (e)	Col. (f)	Col. (g)
<i>percentage ratios</i>								
(Q) SOUTH WALES	—3.43	0.06	87	26	90	7	37	49
Carmarthenshire	—4.45	0.04	93	23	94	4	13	65
Glamorgan	—6.15	0.04	89	42	94	6	53	32
Monmouthshire	—0.70	0.13	88	19	90	6	59	36
Pembrokeshire	—1.20	0.03	78	19	83	13	36	51

The columns show percentage ratios as follows:

- (a) (Lucerne) to (grass)
- (b) (Grass) to (crops + grass)
- (c) (Rough grazing) to (total farm)
- (d) (Grass + rough grazing) to (total farm)
- (e) (Corn + orchard) to (crops + grass)
- (f) (Wheat + barley) to (corn)
- (g) (Oats) to (corn)

Plots were then made of the percentages against the mean soil moisture deficit, and the best curves drawn visually, as shown in Figures 1, 2 and 3. Figure 1 shows the lucerne to grass ratio. In this figure, regional and county

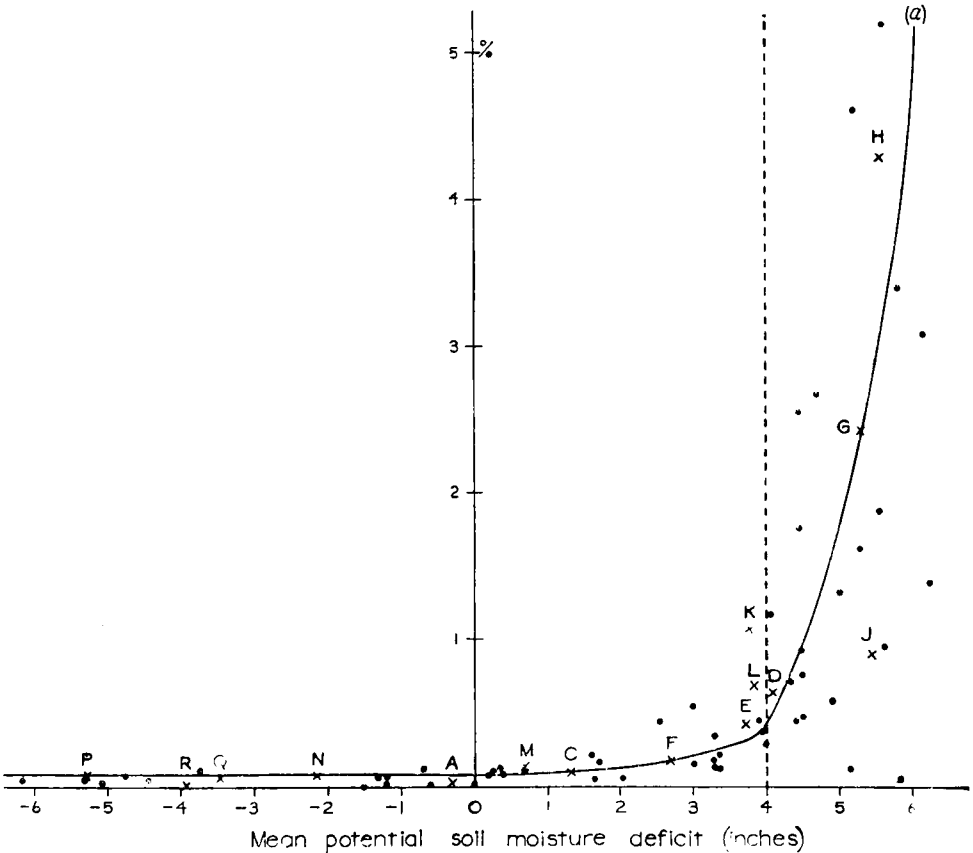


FIGURE 1—PERCENTAGE RATIOS OF LUCERNE TO GRASS IN 1960 FOR REGIONS AND COUNTIES LISTED IN TABLE I COMPARED WITH THE MEAN POTENTIAL SOIL MOISTURE DEFICIT

- x Percentage ratios for regions identified by letters as shown in Table I.
- Percentage ratios for counties listed in Table I.
- Line (a) shows percentage ratio (lucerne) to (grass)—see Col. (a) in Table I.
- — — 4-inch deficit line.

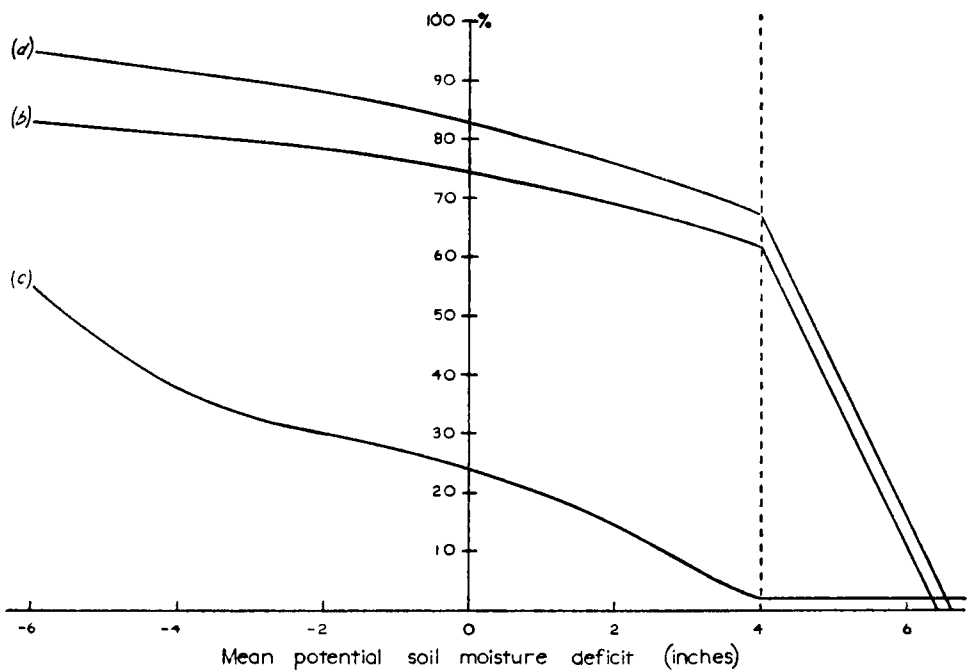


FIGURE 2—PERCENTAGE RATIOS OF GRASSLANDS IN 1960 COMPARED WITH THE MEAN POTENTIAL SOIL MOISTURE DEFICIT

The lines show percentage ratios as follows (see Col. (b), (c) and (d) in Table I):

- (b) (Grass) to (crops + grass)
- (c) (Rough grazing) to (total farm)
- (d) (Grass + rough grazing) to (total farm)
- - - - 4-inch deficit line.

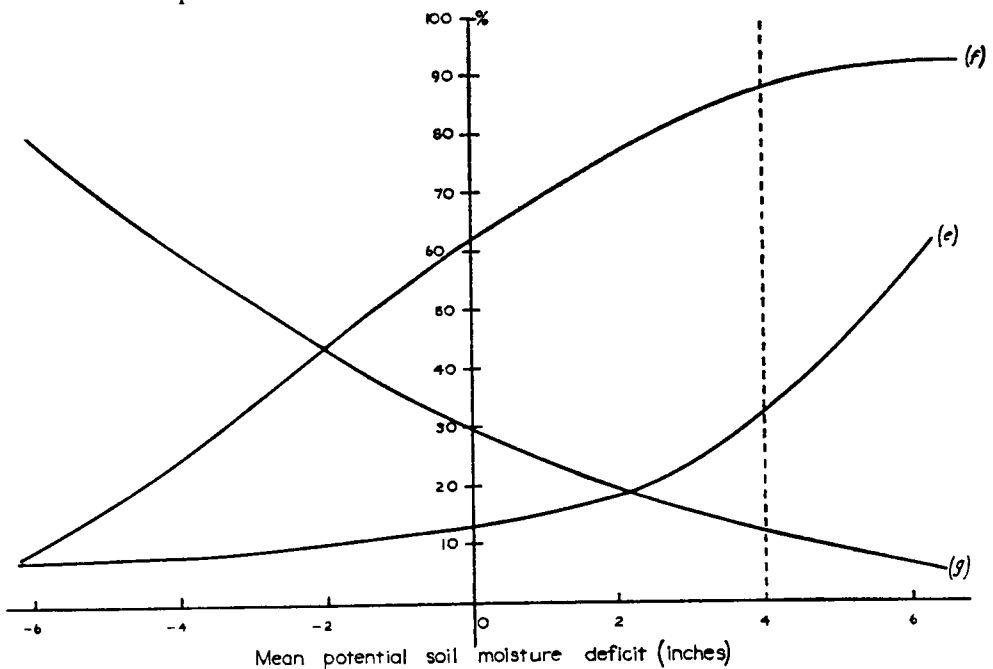


FIGURE 3—PERCENTAGE RATIOS OF CEREAL CROPS IN 1960 COMPARED WITH THE MEAN POTENTIAL SOIL MOISTURE DEFICIT

The lines show percentage ratios as follows (see Col. (e), (f) and (g) in Table I):

- (e) (Corn + orchard) to (crops + grass)
- (f) (Wheat + barley) to (corn)
- (g) (Oats) to (corn).
- - - - 4-inch deficit line.

values are shown, to give some idea of the scatter obtained. Details are not shown in Figures 2 and 3, but there is a similar scatter. In Figure 2 lines (b), (c) and (d) show the grassland ratios and in Figure 3 lines (e), (f) and (g) show the cereal crop ratios.

Discussion.—The resulting lines represent the states of crop distribution which have been reached by independent choice of crops among the farmers of England and Wales. There appears to be a definite relationship between the percentage of land a farmer allots to one particular crop as compared with another crop or crops, and the mean potential soil moisture deficit at the end of August.

Lucerne.—Figure 1, line (a). The percentage of lucerne rises very gradually with increase in potential soil moisture deficit up to a deficit of 4 inches; beyond this point the percentage rises sharply.

Grasslands.—Figure 2, line (b). There is a gradual decline in the percentage of grass to crops and grass with rise of potential soil moisture deficit up to a deficit of about 4 inches. When the deficit rises above this, the percentage of grasslands decreases rapidly.

Line (c). The percentage of rough grazing to total farm acreage falls off fairly steeply with a rise in potential soil moisture deficit up to a deficit of about 4 inches. With a higher deficit than this, the percentage remains at a steady level of about 2.

Line (d). This is very similar to line (b). A gradual decrease occurs in the percentage of grassland to total farm acreage with a rise in potential soil moisture deficit, until the deficit reaches 4 inches. The percentage then drops sharply as the deficit increases.

Cereal crops and orchards.—Figure 3, line (e). The percentage of corn and orchard land to the total crop and grass acreage rises fairly sharply as potential soil moisture deficit increases.

Line (f). The percentage of barley to total corn rises with increasing potential soil moisture deficit, levelling off as the deficit exceeds 4 inches.

Line (g). The percentage of oats to total corn falls off as the potential soil moisture deficit increases, though the falling-off seems to be less steep as the deficit rises above 3 inches.

It is significant that if the potential soil moisture deficit rises above 4 inches, grass shows definite signs of wilting. Lucerne however, continues to grow with a soil moisture deficit above that at which grass dies.

Corn crops and orchard trees both have deep roots, and the pattern of lines (e) and (f) might therefore be expected. The pattern of oats in line (g) is less predictable. However, no account has been taken of any temperature factors, which might provide additional explanation of crop distribution.

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BAROMETRIC PRESSURES IN CENTRAL ICELAND

By I. Y. ASHWELL, M.A., Ph.D.
University of Alberta, Calgary, Canada

Summary.—A method of converting pressures obtained on the central plateau of Iceland during the summer of 1960 to sea level is described. These readings are probably the first obtained in central Iceland from a mercury barometer.

Synoptic charts plotted with the aid of these readings indicate powerful topographical control of the weather, especially under anticyclonic conditions.

Introduction.—Most of the central plateau of Iceland (Figure 1) is an uninhabited desert of rock and sand, at a height of over 300 metres above sea level. Ice-caps occur along the central ridge, running from south-east to north-west, and also along the south coast, with tops rising above 3000 m. A large area of the plateau is enclosed in the ring of the ice-caps Vatnajökull, Hofsjökull, Langjökull and Myrdalsjökull.

During an expedition to this area in the summer of 1951 it was noticed that the ice-cap Hofsjökull generated its own wind system on occasions, and that winds blowing outward from the periphery of the ice-cap then occurred.¹ It was suggested that when a depression travels along the south coast of Iceland the wind systems of the various ice-caps could cause an extension of the low-pressure area into the central plateau, with troughs extending like fingers into the spaces between the ice-caps.

Further work by a succeeding expedition of the British Schools Exploring Society in 1956, the base camp of which was located at Station A (Figure 1(a)), just to the south of Langjökull, showed that 63 per cent of all 144 measured winds during a seven-day period blew from the ice-cap.² It was further noted that, with pressure low to the south of Iceland, and prevailing north-east winds, there was a diurnal pressure fluctuation, when the pressure fell until about midday, and then rose sharply with the onset of a wind from the glacier. It was suggested that under these synoptic conditions, a topographic low was formed in the lee of the ice-caps, although the extent of this phenomenon away from Station A was a matter of inference.³ It was not found possible to deduce sea-level pressures, because the readings were taken from aneroid barometers, and only differences between the readings at Station A, and those at Reykjavik, on the coast, were considered. However, it was clearly desirable to carry out an investigation with a mercury barometer, and to try to establish some correlation with sea-level values.

A third expedition in the summer of 1960 was based at Station B (Figure 1(a) and Plate I). Two Meteorological Office long-range mercury barometers were carried with the expedition, but despite the greatest care in handling, one was found to be broken on arrival at Station B. The other performed satisfactorily for an observation period from 31 July to 7 September. Although there was no check on this instrument in the field, it was found, when checked by the Instruments Division of the Meteorological Office, to be subject to the original corrections applied in the field. Whilst this is not absolute proof of its accuracy in the field, the results obtained with the instrument suggest that it was accurate. This paper is concerned with these results.

Local conditions.—The base camp was sited some 4 km from the north-eastern edge of Langjökull, at the base of the low range of hills bordering the

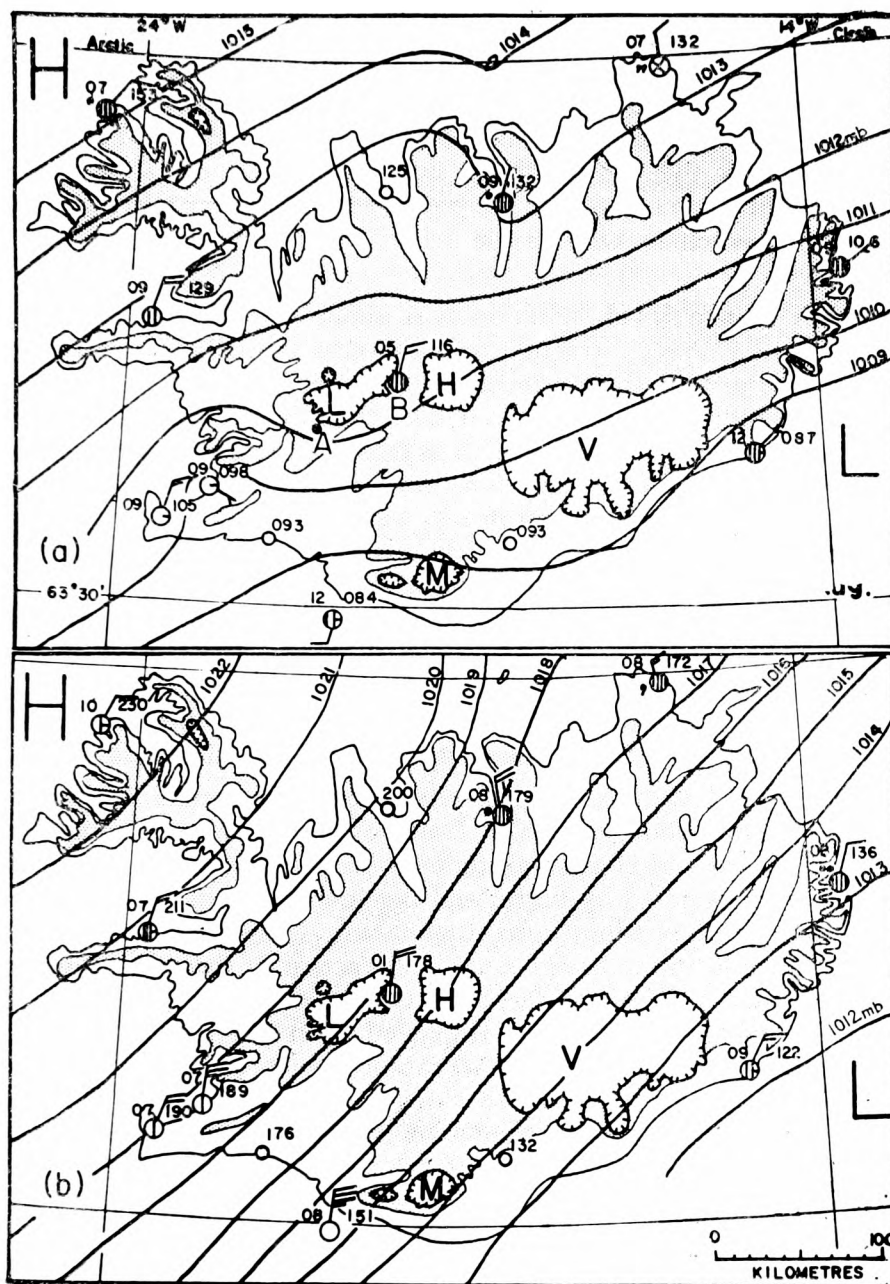


FIGURE 1—SYNOPTIC SITUATIONS WITH GENERALLY NORTH-EAST WINDS OVER ICELAND

Land over 300 metres is shaded. Isobars are at 1-mb intervals.

Ice-caps: V - Vatnajökull M - Myrdalsjökull

H - Hofsjökull L - Langjökull

(a) 0000 GMT on 15 August 1960

A - Site of observations in 1956. B - Site of observations in 1960.

Clearer skies and disturbance of the isobars in the south-west indicate some topographical control of the weather.

(b) 0000 GMT on 17 August 1960

Strong winds allow of little topographical control.

ice-cap. The barometer was set up in a tent, and was mounted on a strong wooden pole sunk a metre into the ground. Corrections were applied to each reading for gravity, instrument error, and instrumental temperature; these corrections were consolidated into a table for convenience. The readings were thus only corrected for the station level of 695 m above sea level. This level is possibly a metre or two on the high side, since the nearest geodetically-established height is some 12 km to the north, and the survey over this distance could not be expected to keep to the original accuracy of the triangulation point.

Correction to sea level.—Station B is about 100 km from the sea and 695 m high so that direct correction to sea level is virtually impossible by the use of the simple pressure-height formula. The situation is complicated by the fact that in Iceland, in summer, the air over the sand and rock of the central plateau heats up to temperatures as high as those on the coast, and assumptions of normal temperature gradients become untenable. The problem of correction for synoptic purposes can be solved in two ways.

The first is perhaps the most satisfactory for such an isolated area, and involves correction upwards to one of the standard pressure surfaces. This was used with success in the relation of pressures on the summit of the Greenland ice-cap to the 700 mb charts.⁴ However, in that case, the altitude difference between 'Northice' station and the 700 mb surface was never very great. In the present case, with pressures near 900 mb it was felt that this method of correction upward would not have been adequate for the detailed results required.

The method used was the second alternative, a correction down to sea level. In the central plain regions of North America, the same problems of distance from oceans and of great altitudes above datum level also exist. These problems were investigated by Ferrel and Bigelow. By a painstaking review of the observations and previous correction factors, Bigelow⁵ drew up recommendations which form the basis for present practice. It should be pointed out here that, although the formula to be discussed below is based on theoretical considerations, some of the values employed in it are dependent on local factors found by a long series of observations which are lacking in central Iceland. It has been found convenient in this discussion to use the practice developed in Canada (Meteorological Branch, Department of Transport)⁶ as being more relevant to Icelandic conditions.

The reduction equation.—As put forward by Bigelow, this equation was in the form

$$p_o = p_s + (dp + a + b + c) \quad . . . (1)$$

where p_o is sea-level pressure,

p_s is station pressure,

dp is the weight of the fictitious column of air extending from sea level to the station level, and computed from the hypsometric formula,

a is the so-called plateau correction of Ferrel,

b is a correction for the assumed mean value of humidity of the fictitious air column,

c is a term originally introduced to even out inconsistencies in corrected readings. It is now largely ignored because of improvements in the other factors.

In this equation, the term dp is derived by integration of the hypsometric formula to an exponential expression, and subsequent expansion as an infinite series. The later terms of this series are ignored, being so small as to contribute a negligible error compared with those of other factors.

This results in

$$p_0 - p_s = p_s \frac{490}{460 + T_M} \left\{ x + \frac{x^2}{2} \right\} \quad \dots (2)$$

where T_M = mean temperature at time of observation in °F. To eliminate diurnal changes, the practice is to make $T_M = \frac{1}{2} (t_h + t_{h-12})$ where t_h is the temperature for h , the hour of observation, and t_{h-12} is the temperature 12 hours previous to h ,

$x = h/26111$ where h is the elevation of the station above sea level in feet.

In equation (1) the plateau correction a is given by

$$a = C \times \Delta T \times H_s \quad \dots (3)$$

where C = constant (0.0355 for mb units),

H_s = elevation of station in 1000's of feet above sea level,

ΔT = difference between T_M , the mean air temperature at time of observation and T_s , the mean annual temperature of the station.

In equation (1) the humidity correction b is, in Canadian practice, deduced from the Smithsonian tables⁷ for the relevant height and T_M conditions.

Sources of error in the equation.—The potential sources of error probably lie in the following terms:

- (i) In equation (2), h , elevation above sea level; only by a detailed levelling survey would it be possible to be certain that any height in central Iceland was closer than ± 2.5 m to the correct height.
- (ii) In equation (3), ΔT , the difference between the mean temperature of the observation period and T_s , the mean annual temperature, is uncertain because the term T_s is almost completely unknown. This is discussed below.
- (iii) H_s suffers from the same lack of surveyed accuracy as h above. The humidity correction b is assumed to be for normal conditions. However, because of adiabatic warming, central Iceland often has relative humidity values as low as 20 per cent and, when more accurate values of other terms are obtained, it would seem that a recalculation of the term b for more representative conditions of plateau humidity is advisable.

The mean annual temperature T_s .—Although no stations have been operated on the high plateau of Iceland near the ice-caps for a continuous period long enough to obtain an annual temperature, readings have been made for over half a century at Grimsstadir on the lower edge of the plateau at G (see Figure 2(a)). Station B lies about half-way between Grimsstadir and Reykjavik (R in Figure 2(a)) in the south-west.

In August 1960, Reykjavik had a mean temperature 0.6°C above the average of 10.6°C , while Grimsstadir registered 1.0°C below its average of 7.2°C .⁸ It seems probable that, like Reykjavik, Station B had conditions giving temperatures slightly above average. The measured mean temperature for Station B

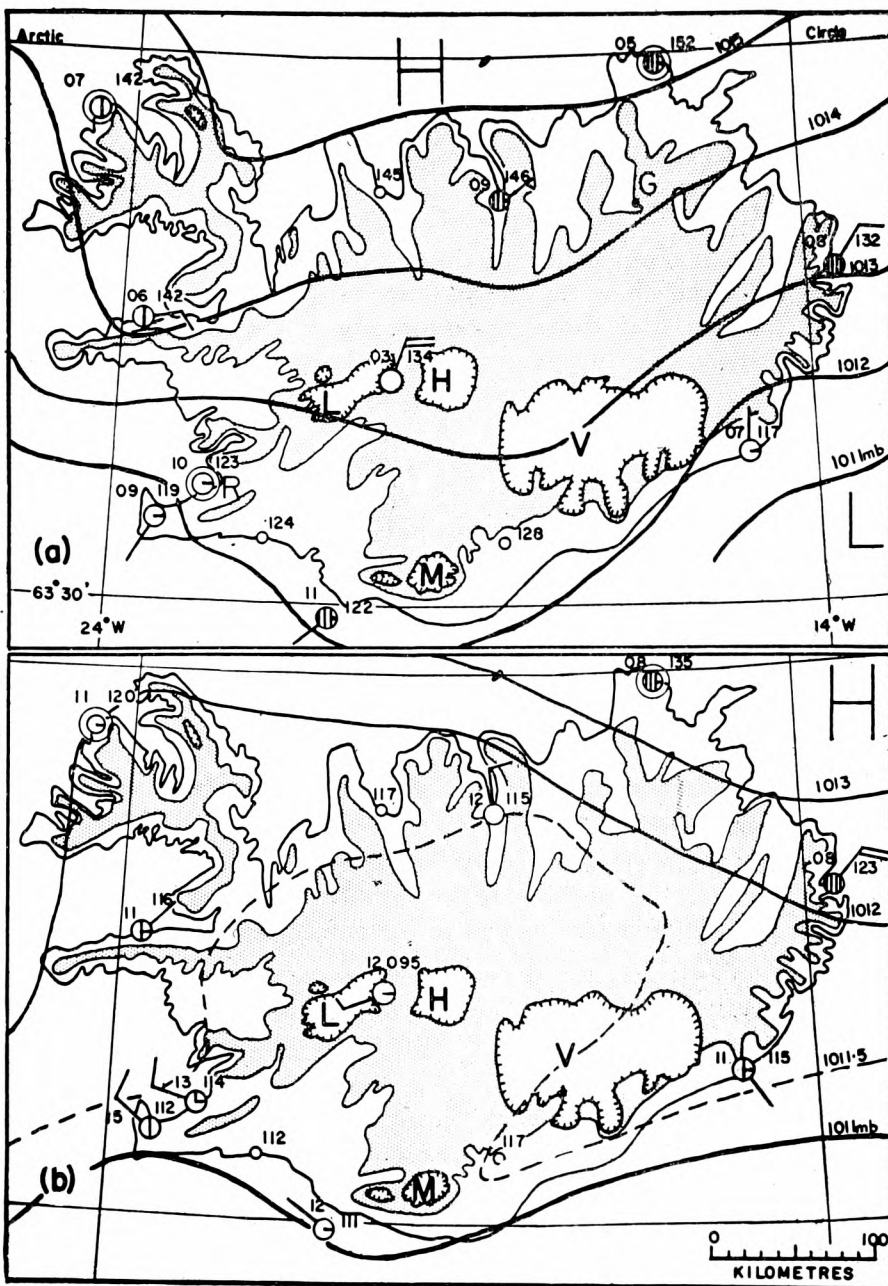


FIGURE 2—SYNOPTIC SITUATIONS WITH LIGHT NORTH-EAST WINDS
OVER ICELAND

R - Reykjavík G - Grimsstadir

Other details as in Figure 1.

(a) 0000 GMT on 19 August 1960

Slack anticyclonic gradient at night.

(b) 1500 GMT on 19 August 1960

Low pressure over the central plateau in mid-afternoon.

was 6.3°C and it is asumed here that the mean for August is 6.0°C. This may well be a high estimate especially since the difference in altitude between Station B and Grimsstadir would indicate a lower average at Station B.

The march of temperature at stations in Iceland differs considerably depending on the altitude of the station and its location. Reykjavik, in a marine environment, has a much more moderate climate than Grimsstadir although the summer temperatures are closer together⁸ (Table I). It seems likely that Station B has a continental type of temperature régime similar to that of Grimsstadir. If, therefore, it is assumed that the temperature curve is of the same type as that of Grimsstadir and that the mean annual temperature of Station B is 1.2°C below that of Grimsstadir, as was the mean in August, then T_s for Station B will be -0.7°C. This is likely to be high on many accounts, and in particular because of the proximity of Station B to the ice-cap Langjökull, whereas Grimsstadir is far from any of the ice-caps.

TABLE I—MEAN MONTHLY TEMPERATURES AT REYKJAVIK AND AT GRIMSSTADIR

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						<i>degrees Celsius</i>							
Reykjavik	-0.6	-0.2	0.5	2.6	6.3	9.6	11.3	10.6	7.8	4.3	1.4	0.0	4.5
Grimsstadir	-5.6	-4.9	-4.5	-1.7	2.1	7.1	9.6	7.2	4.2	0.1	-3.6	-4.9	0.5

Reykjavik is 17.8 m and Grimsstadir 385.9 m above MSL.

At the other extreme, figures are available for the Britannia Sö Station of the British North Greenland Expedition, at a higher latitude (77°N) but a lower altitude (231 m) than Station B. This station lay just to the east of the Greenland ice-cap. Figures for two 12-month periods gave annual mean temperatures of -9.5° and -10.0C.⁹

For the purpose of this paper, a mean annual temperature has been estimated at a point on the scale about half-way between conditions at Grimsstadir and those in Greenland. T_s for Station B is thus assumed to be -5.0°C, and an error of a few degrees will not make much important difference to the size of the correction factor in equation (3).

Calculation of the correction factor.—Changes have been made in equation (1) to allow for use of altitudes in metres instead of feet, and °C instead of °F.

Using the following values $h = 695$ m and $T_s = -5.0^\circ\text{C}$, equation (2) becomes

$$dp = p_s \times \frac{273}{273 + T_M} \times 0.09109$$

and equation (3) becomes

$$a = 0.04499 (T_M + 5).$$

These two factors have been combined into the correction factors in equation (1) which become

$$p_s \times \frac{273}{273 + T_M} \times 0.09109 + 0.4499 (T_M + 5) + b.$$

Table II shows the main values of corrections for the ranges of temperature and pressure experienced at Station B.

Typical synoptic situations.—Values derived from Table II are used to illustrate situations occurring with low pressures to the south of Iceland. The

TABLE II—CORRECTIONS TO BE ADDED TO READINGS OF PRESSURE AT STATION B
FOR REDUCTION TO SEA LEVEL

Mean station temperature, T_M degrees Celsius	Station pressure, p_s , in millibars					
	920	925	930	935	940	945
	Correction to be added millibars					
0	83.88	84.34	84.79	85.25	85.70	86.16
1	83.60	84.06	84.51	84.96	85.42	85.87
2	83.32	83.78	84.23	84.68	85.13	85.58
3	83.05	83.50	83.95	84.40	84.85	85.30
4	82.77	83.22	83.67	84.12	84.57	85.02
5	82.50	82.96	83.39	83.84	84.29	84.74
6	82.23	82.68	83.12	83.57	84.01	84.46
7	81.96	82.41	82.85	83.29	83.74	84.18
8	81.70	82.14	82.58	83.02	83.47	83.91
9	81.43	81.87	82.31	82.76	83.20	83.64
10	81.17	81.61	82.05	82.49	82.93	83.37
11	80.91	81.35	81.79	82.23	82.66	83.10
12	80.65	81.09	81.53	81.96	82.40	82.84

Station B is 695 m above MSL.

flow of air in a generally north-easterly direction is controlled markedly by the local conditions over Iceland. With strong winds and thick cloud cover, the isobars run straight over the country (Figure 1(b)), but with moderate wind-speeds, local interruptions to air flow occur (Figure 1(a)). With clear skies on the outskirts of an anticyclone, pressure over the central plateau in mid-afternoon is low (Figure 2(b)). The low pressure is indicated particularly by Station B, but to a lesser extent also by the stations surrounding the plateau and by the onshore winds which were observed.

Acknowledgements.—Thanks are due to the Meteorological Office, London, to the Meteorological Branch, Department of Transport, Canada, and to the Icelandic Weather Office, for help with instruments and advice. The observations were carried out by members of the 1960 Expedition of the British Schools Exploring Society, and the author wishes to thank, in particular, his fellow meteorologist, Mr. N. G. Brown, and the boys who did the hard work of continuous observation.

The working-up of the results has been aided by a grant from the Research Fund of the University of Alberta.

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* See also 'Present methods used by the Canadian Meteorological Branch for reducing atmospheric pressure to mean sea level' an unpublished office memoranda of the Department of Transport, Meteorological Branch, Canada.

SYMPOSIUM ON THE BIOLOGICAL SIGNIFICANCE OF CLIMATIC CHANGES IN BRITAIN

By J. G. COTTIS

Many disciplines were represented at the Institute of Biology's symposium held in London on 29 and 30 October 1964, to examine the nature and magnitude of Britain's climatic changes in relation to biological responses, especially those of importance to agriculture.

The theme of the first session was the assessment of the dimensions of climatic change, the opening speaker being Mr. H. H. Lamb of the Meteorological Office. He outlined the main stages of Britain's climatic history over the past 10,000–15,000 years, treating the last 1000 years in more detail; he described the remarkable warming of our climate over the period from about 1890 to the 1930's, which affected the length and dependability of the plant growing season, but warned that extrapolation of the climatic reversal since about 1940 is no guide to the future. Climatic forecasting must await a better understanding of the physical influences and mechanisms involved, particularly in the general circulation.

It is currently fashionable to accept that climate is changing but Lamb warned that the facts must be put into proper perspective, which only fuller knowledge and careful numerical assessment can give. He dealt quantitatively with recent trends of temperature, rainfall, lying snow, etc., relating these to selected agricultural and horticultural practices (such as trying to grow exotic fruit crops, e.g. apricots, peaches and grapes), and demonstrated changes in circulation of wind and ocean currents.

Professor D. J. Crisp of the Marine Science Laboratory, Anglesey, spoke on the effects of climate and weather on marine organisms and stressed the distinction between average climatic conditions on the one hand and isolated periods of abnormal weather on the other. It seems that gradual changes in the climate over a number of years are more effective in modifying the general pattern of distribution of species than are relatively short periods of severe weather such as the cold winter of 1962–63. Dr. J. A. Taylor of the University College of Wales followed with a paper on climatic change as related to soil variables and altitudinal thresholds; taking examples from the maritime uplands he discussed how undisturbed soil profiles can help to register the ebb and flow of ecological frontiers in response to changes of climate. He also described some well-marked changes of distribution of bracken and molinia grass in Wales in recent decades and related these to climatic variation but, in subsequent discussion, doubts were raised as to whether such distribution changes could fairly be regarded as effects of climate variation in view of known changes of grazing management and land use.

The afternoon session selected some effects of climatic change and their implications, and covered a wide range of subjects. Dr. F. H. Perring of the Nature Conservancy discussed the advance and retreat of the British flora but he stressed that change in climate, or macroclimate, is but one factor involved and that man's disturbance of the environment often over-rides other factors. Mr. R. J. H. Beverton and Mr. A. J. Lee of the Ministry of Agriculture, Fisheries and Food Fisheries Laboratory at Lowestoft, outlined recent changes in distribution of cod and herring, and described how these may be related to variation in sea temperatures.

Professor F. L. Milthorpe of Nottingham University said there is little doubt that variations in climate are responsible for appreciable variations in yields of agricultural crops even in countries as free of catastrophic changes as Britain, but he described attempts to derive quantitative relationships between plant yield and the weather components as having been largely unsuccessful because of inadequate definition or understanding of the environmental variables. Nevertheless he asserted that much progress had been made towards understanding the environmental needs of a crop for optimum growth and yield. Professor J. P. Hudson, also of Nottingham University, dealt with the agronomic implications of long-term weather forecasting, reminding us that climate limits the choice of crops and varieties while weather causes deviations from the expected levels of yields; more knowledge is needed on the response of plants, and varieties of plants, to weather. Developments in long-range weather forecasting suggest many interesting possibilities for prediction and control of seasonal and varietal yields, and in the planning and management of crops.

The opening speaker on the second day of the symposium was Mr. W. H. Hogg of the Meteorological Office, who examined the climatic factors involved in choice of site, particularly for horticultural crops. He gave examples of how standard (macroclimatic) data are applied to choice of site for crops but emphasized that mesoclimatic factors must be carefully considered in relation to the horticultural potential of any area. At present our knowledge of local deviations from the macroclimate is sketchy, especially in country of varied topography, and he suggested a number of specific topics on which more information would be valuable.

Dr. K. L. Blaxter of the Hannah Dairy Research Institute related climatic factors to the productivity of different breeds of livestock. His paper was concerned with the direct effects of cold on farm stock and with comparative aspects of cold tolerance. The distribution of breeds of cattle in Britain still reflects in some respects their source of origin but there is little evidence that climatic factors play much of a role in determining distribution now, largely because of improved farming technology; however, there are distinct differences in the cold tolerance of hill sheep compared with lowland breeds. Dr. Blaxter explained that cold tolerance in animals was increased by better feeding so that adequate nutrition combined with the provision of simple shelter was the best insurance against a severe winter.

Climatic adaptation of local varieties of forage crops was the subject of the paper read by Dr. J. P. Cooper of the Welsh Plant Breeding Station. He described the main climatic factors limiting crop production in the Mediterranean, European, and maritime Atlantic regions, and gave some experimental results. Over much of eastern Britain average winter temperatures and summer precipitation are both marginal for active growth so that comparatively small seasonal or altitudinal changes in either temperature or water supply have a disproportionately large effect on the length of the growing season. Dr. Cooper ended with a plea for more detailed studies of field environment, especially of the microclimate in and around a crop.

Mr. L. P. Smith of the Meteorological Office opened the final session of the symposium by discussing possible changes in our seasonal weather, emphasizing that these were not to be regarded as forecasts but that he was intent on examining aspects of present-day farming practice that were most sensitive to

possible future climate changes. Some changes would be generally regarded as beneficial to British agriculture but the main threat of increased difficulties leading to depressed yields or lower profitability appeared to him to come from the possibility of drier winters (inadequate replenishment of natural water storage), colder springs (a later start to growth), wetter summers (haymaking and grain harvesting more difficult, with greater disease problems) and wetter autumns (presenting difficult operational problems, especially on heavy land). More simply, coldness and wetness at both ends of the growing season would be the most serious threat.

Professor A. N. Duckham of Reading University presented the last paper, on 'Agricultural Perspectives', expressing confidence in farmers' capacity to cope with the effects of possible climate changes, partly because of the vast increase in available power. He discussed the weather sensitivity of tillage crops and thought that further mechanization, irrigation and better weather data, together with agronomic advances, will enhance the reliability of such crops. Professor Duckham went on to survey other weather sensitive-aspects of British farming. In subsequent discussion, he suggested that if our summers became wetter and cooler and conditions were too difficult for cereals—for example in East Anglia—then farmers would naturally adopt the alternative of root crops and grass; but he pointed out that the resilience of British agriculture was bought at a high price, that of costly machinery and fertilizers.

The Chairmen at the four sessions were Mr. L. P. Smith, Professor A. H. Bunting (Reading University), Professor J. E. Nichols (University College of Wales) and Sir Joseph Hutchinson (School of Agriculture, Cambridge University).

With twelve papers to consider or digest, there was insufficient time for much general discussion. Apart from questions seeking clarification or elaboration of points raised in the papers, discussion ranged over such matters as the possible misuse of statistical handling of data, economic and political considerations, the prospects of improved mechanization, the loss of agricultural land to urban growth, the potential value of upland sites and land reclamation generally.

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WEATHER SATELLITES WILL HELP AUSTRALIAN FORECASTERS

By N. CARRICK

News and Information Bureau, Australia.

Australia's weather forecasting facilities will be vastly improved when weather satellites regularly orbit the earth.

The first NIMBUS satellite transmitted such valuable information to two 'read-out' stations in the State of Victoria that three new stations, at Perth, Western Australia; Darwin, Northern Territory and Brisbane, Queensland, are planned. NIMBUS A, launched by the United States National Aeronautics and Space Administration (NASA) from Vandenberg Air Force Base, on 28 August 1964, stopped transmitting signals when its two solar paddles jammed recently. However, the United States plans to launch another satellite soon and to have satellites continually in orbit.

Australia, like other countries in the southern hemisphere, has its weather pattern dominated by air masses which move across the continent from mainly the south-west, and sometimes from the north. As there are no weather stations

in the southern part of the Indian Ocean and the Southern Ocean, and as few ships which could radio information ply these seas, Australian meteorologists suffer from a serious lack of detailed information of cloud formations in these areas. The first NIMBUS satellite, which orbited the earth each 98 minutes at a height of 575 miles, relayed to 'read-out' stations photographs of cloud formations (Plate II) which assisted meteorologists to make forecasts. Victoria had two 'read-out' stations receiving photographs from NIMBUS A while it was transmitting. One was at the Royal Australian Air Force Base at Laverton near Melbourne (Plate III), and the other at the University of Melbourne.

NIMBUS A, when passing in range of the two stations, transmitted signals which were then relayed to the Bureau of Meteorology in Melbourne. The signals were then taped and fed through a facsimile machine operated on the same principal as a normal picturegram unit. The resulting pictures showed cloud formations over a vast area—and also showed one extremely interesting sidelight. The photographs taken from 575 miles up showed the southern Australian coastline clearly—and proved just how accurate the map makers were.

Australian authorities hope to have the 'read-out' station in Perth completed soon and the other two in Darwin and Brisbane within the next few years.

REVIEWS

Weatherwise, the technique of weather study, by N. L. Peter. 8 in \times 5½ in, pp. ix + 179, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1964. Price: 25s.

This book, intended primarily for yachtsmen, scans many aspects of meteorology, and the author attempts to discuss not only weather typical of the British Isles and its coastal waters but also that of other parts of the world, particularly the tropics and Australia. Also included is a section on oceanography, a subject closely allied to meteorology but only rarely mentioned in elementary meteorological texts.

Much ground is covered in less than 200 pages and simplification of many concepts is inevitable. Unfortunately some chapters suggest that the author lacks a clear understanding of his subject. When at a loss to explain the physical or meteorological relationship between two concepts he frequently resorts to using the verb 'to tend' or the noun 'tendency.' The most unsatisfactory section is that on Visibility where the reader would be both confused and misled. In addition the book contains numerous factual errors. It is expensive at 25s. and in the reviewer's opinion cannot be recommended.

D. M. HOUGHTON

Meteorology and climatology for sixth forms and beyond, second edn by E. S. Gates. 9½ in \times 7½ in, pp. 207, *illus.*, George G. Harrap & Co. Ltd., 182 High Holborn, W.C.1, 1963. Price: 16s.

This book was first published in 1961, and was reviewed in the *Meteorological Magazine* in October 1961.

In this edition the author has made slight amendments to the text and certain diagrams. There is some confusion regarding the tropopause and this needs to be rectified, e.g. on p. 115 there is a statement about "aircraft which

now operate outside the troposphere and well within the tropopause," and on the same page there is a reference to "this transition zone" which would seem to imply that the tropopause is a layer of some considerable thickness. It is also surprising to find in Figure 105, that Vancouver is still selected as an example of a west European climate.

The book has been improved by a considerable extension of the bibliography, and by the addition of four appendices, one of which gives monthly and annual values of temperature and precipitation for over 450 stations throughout the world.

Although the book is intended primarily for the geography student, it should prove stimulating to the young physicist and to the keen amateur.

W. R. GALLOWAY

Physics of the air, by W. J. Humphreys. 8½ in × 5½ in, pp. xvi + 676, *illus.*, Constable & Co. Ltd., 10 Orange Street, W.C.2, 1964. Price: \$3.

The first edition of this classic textbook appeared in 1920, and was followed by the second and third editions in 1929 and 1940. The present 'Dover Edition' is an unabridged reprint of the third edition.

With the advance in knowledge of the atmosphere which has occurred since 1940, many parts of the book have become obsolete: in particular, is this true of the physics of the upper atmosphere of which little was known in 1940. The section dealing with atmospheric optics, however, is still a standard reference on the subject.

W. R. GALLOWAY

NOTES AND NEWS

Canadian Meteorological Service

Mr. J. R. H. Noble has been appointed as Director of the Meteorological Branch of the Department of Transport. Dr. T. G. How was named in an earlier announcement in the *Meteorological Magazine* of July 1964 but declined the appointment for health reasons.

Irish Meteorological Service

Mr. A. Bourke has been appointed to succeed the late Dr. M. Doporto as Director of the Irish Meteorological Service. Mr. Bourke is at present Vice-President of the International Society of Biometeorology.

LETTER TO THE EDITOR

202 Meteorological Reconnaissance Squadron

Having had almost continuous connexions with both No. 202 Squadron and Meteorological Reconnaissance Flights over a long period, I found the article by Mr. R. F. M. Hay in the November 1964 *Meteorological Magazine* most interesting.

One incident which is not recorded is worthy of note. During its war-time service at Gibraltar No. 202 Squadron was engaged on normal Coastal Command operations, the Gibraltar meteorological flights ('Nocturnal') being performed by Halifax aircraft. In 1944, however, the availability of serviceable

Halifax aircraft became so low that for a period regular meteorological sorties could not be made. To ease the situation, it was arranged that some flights would be taken over by the Catalina aircraft of No. 202 Squadron. Instruments were fitted in a very simple manner, air meteorological observers joined the regular flying-boat crew and the first meteorological flight was made by the Squadron on 28 June 1944. The full 'Nocturnal' track was followed, with some limitation to, I believe, about 10,000 ft, in the height of the vertical ascent. Except in this respect the flight was entirely normal and highly successful and was repeated on several subsequent occasions during the following weeks.

This was probably the first full meteorological flight to be performed by an RAF flying-boat, and certainly the first to be performed by No. 202 Squadron, which was later to become so closely associated with 'Bismuth' until its termination in 1964.

Meteorological Office, Bracknell

A. L. MAIDENS

HONOUR

The following award was announced in the New Year Honours List, 1965:

B.E.M.

H. D. Henley, Technical Class Grade III, Meteorological Office, Kew Observatory. Mr. Henley retired from the Office on 26 September 1964.

THE METEOROLOGICAL MAGAZINE

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SIR GEORGE SIMPSON, K.C.B., C.B.E., D.Sc., LL.D., F.R.S.

It is with deep regret that we report the death of Sir George Simpson on 1 January 1965, at the age of 86. He was Director of the Meteorological Office from 1920 to 1938.

George Clarke Simpson was born at Derby in 1878 and was educated at the Diocesan School, Derby, and the Victoria University of Manchester, where he graduated in physics. In 1903 he gained an '1851 Exhibition' and went to study at Göttingen. During this period he also investigated atmospheric electricity in Lapland. On his return to England he became lecturer in meteorology at Manchester and in 1906 was awarded the D.Sc. of that university. In the same year he left England to join the India Meteorological Department in whose service he remained until 1920 except for a two-year absence with Scott in the Antarctic between 1910 and 1912. Here he was engaged as physicist and meteorologist and the work that he did then, ensured that he will always be remembered as one of the pioneer meteorologists of Antarctica. He was elected to the Royal Society in 1915.

In 1920 he succeeded Sir Napier Shaw as Director of the Meteorological Office. The decision had been taken to unite all the meteorological services that had been formed in the war into one service within the Air Ministry, and to Dr. Simpson (as he then was) fell the formidable task of carrying out this policy. At this time one need was paramount—to shape the official meteorological services so that the rapidly growing needs of aviation, both military and civil, could be met. It was here that Simpson's skill as an administrator became evident and when, one year after his retirement, the Second World War began, the Office was able to expand rapidly into the very large organization needed to cope with the demands of the armed forces, especially the RAF, during the years of conflict. He returned to the Meteorological Office in 1939 to take charge of the Observatories, a task very much to his liking, and finally retired from active work in 1946, at first to Putney and later to Somerset.

Of Simpson's scientific work more will be written, no doubt, in memoirs elsewhere and here only a brief summary can be given. His name will always be associated with the theory of charge separation in thunderclouds. The Simpson theory, which was based mainly upon the concept that electrification of thunderclouds is produced mainly by the break-up of drops and by collisions and friction between ice crystals, was long a matter of keen debate among

meteorologists, especially when contrasted with rival theories, such as the ion-capture process advanced by C. T. R. Wilson. Simpson's work on thunder-storm theory forms a notable chapter in the history of meteorology.

Another memorable piece of work was his analysis of the radiation balance between the sun and the earth. Mathematically, the problem is almost intractable because of the complex nature of the water-vapour absorption spectrum in the infra-red. Simpson overcame these difficulties by physical insight, adopting a bold simplification of the spectrum into opaque, transparent and semi-transparent bands that enabled him, by simple planimeter measurements, to account quantitatively for the main features of the balance. Finally, mention must be made of his preoccupation in later years with past climates, culminating in his 1959 paper in the *Quarterly Journal of the Royal Meteorological Society* on world temperatures in the pleistocene, a remarkable feat for a man over 80 years of age.

During his 18 years as Director, Sir George not only created an efficient organization but gave considerable attention to the social activities of the Office, especially in sport. He also did much valuable work in the international field and was a well-known figure in the International Meteorological Organization.

He married, in 1914, Dorothy Stephen of Sydney, Australia, and they had three sons and one daughter. To Lady Simpson and the family we send our sincere condolences on their loss.

O. G. SUTTON

551.508.29:551.526.6:311.214

THE STANDARD ERROR OF A SEA SURFACE TEMPERATURE AS MEASURED USING A CANVAS BUCKET

By M. W. STUBBS

Summary.—From 492 canvas bucket observations of sea temperature obtained on voyage six of *Weather Surveyor* in 1962, the standard error of a single observation was deduced, with 95 per cent confidence limits to be $0.202 \pm 0.013^{\circ}\text{F}$ ($0.112 \pm 0.007^{\circ}\text{C}$). This is an upper limit to the instrumental error since it was impossible from the data to separate the instrumental error from the small spatial and temporal fluctuations of the sea temperature; a complete programme of paired observations is required before these latter errors may be separated from the instrumental errors.

Introduction.—The measurement of sea surface temperature from the British Ocean Weather Ships is by means of a canvas bucket when the ship is 'on station' and an insulated bucket when she is 'under-way.' An estimate of the accuracy of the measurements using the canvas bucket is desirable. Provided the errors are normally distributed, the root mean square error or the standard error is a convenient measure of the accuracy since two-thirds of the errors lie in the range plus or minus the standard error. Sufficient data were obtained on voyage six of *Weather Surveyor* in 1962 to define an upper limit to the standard error; *Weather Surveyor* was on station 'Juliet' during voyage six.

Errors in the measurement of the sea surface temperature.—The sea surface temperature is obtained by lowering the canvas bucket into the water over the stern of the ship; it is hauled back on board and the thermometer is placed in the water in the bucket; after about half a minute the thermometer is read.

Ashford¹ has discussed the errors that can arise in this temperature due to the ambient wet-bulb temperature being different from the sea temperature. During voyage six the wet-bulb temperature was, on average, 2.27°C lower than the observed sea temperature; from Ashford's results this deficit would result in an average fall of temperature of water in the bucket of 0.01°C per minute, whilst the largest deficit of 6.9°C would have resulted in a fall of 0.04°C before the thermometer was read. These values are an order of magnitude lower than the standard error found below but may be regarded as a systematic error in the bucket temperature if no correction is applied to the readings.

Although the instrumental error is of interest in this note, local temporal and spatial fluctuations of sea surface temperature can result in the observed value not being a true representation of the sea surface temperature. Amot², for example, has discussed the heating effect of the hull of the ship, especially when the sun is shining; he found that the sea temperature can be raised in such conditions by 0.1° to 0.3°C from its initial value up to a distance of 10 metres from the hull of the vessel.

Stevenson³ has described how the bucket temperature may be lower than its representative value because of the effect of wind on the hull of a ship; the wind can cause upwelling of water from the region of the keel of the vessel on the lee side. This effect is most marked if there is a definite temperature gradient in the upper layer of the sea. According to Stevenson the fall of temperature associated with this effect can amount to 0.5°F (0.3°C).

Marked inhomogeneities of temperature also exist in the open sea. These can be caused by several factors, changing winds, turbulent overturning and the effect of ocean currents being a few possible causes. The standard error deduced below includes all these errors and may therefore be considered as an upper limit to the instrumental standard error of the method.

The standard error of a bucket observation.—The bucket temperature θ_n measured at hour n may be written in the form:

$$\theta_n = T_n + F_n + e_n \quad \dots (1)$$

where T_n is the representative temperature of the water, F_n is the magnitude of the errors due to the small local fluctuations of temperature and e_n is the magnitude of the errors due to the instrumental errors. The observed temperature j hours later, θ_{n+j} , can be written as:

$$\theta_{n+j} = T_{n+j} + F_{n+j} + e_{n+j}. \quad \dots (2)$$

On subtracting (1) from (2) and squaring both sides of the new equation, then summing over all the pairs of temperature measurements j hours apart:

$$\Sigma(\theta_{n+j} - \theta_n)^2 = \Sigma(T_{n+j} - T_n)^2 + \Sigma F_{n+j}^2 + \Sigma F_n^2 + \Sigma e_{n+j}^2 + \Sigma e_n^2 + \dots \text{cross terms} \quad \dots (3)$$

Now $\Sigma F_{n+j}^2 \simeq \Sigma F_n^2$ and $\Sigma e_{n+j}^2 \simeq \Sigma e_n^2$. It can also be shown that there is little or no relation between T , F and e , thus the cross terms may be neglected. Dividing (3) by N_j , the number of pairs of observation j hours apart, gives

$$\frac{\Sigma(\theta_{n+j} - \theta_n)^2}{N_j} = \frac{\Sigma(T_{n+j} - T_n)^2}{N_j} + s^2 \quad \dots (4)$$

$$\text{where } s^2 = \frac{\Sigma F_n^2 + \Sigma e_n^2}{N_j}$$

Now $N_j = N - j$ where N is the number of observations, so that when $j = 0$;

$$s^2 = \frac{\Sigma F_n^2 + \Sigma e_n^2}{N}$$

i.e. s^2 is the variance due to local spatial fluctuations of the sea temperature and the instrumental errors.

In equation (4) when $j = 0$ the term $(T_{n+j} - T_n)^2/N_j$ vanishes and

$$\left[\frac{\Sigma (\theta_{n+j} - \theta_n)^2}{N_j} \right]_{j=0} = 2s^2 \quad \dots (5)$$

The term on the left cannot easily be measured and, in fact, pairs of observations were not made but the graph of $\Sigma (\theta_{n+j} - \theta_n)^2/N_j$ against j can be constructed, and a value for the left-hand term obtained by extrapolation assuming that the graph is linear. In equation (4) the differences between pairs of temperatures may be expected to increase with increasing values of j whilst the term in s^2 is likely to remain almost constant.

Results.—On voyage six, 492 hourly observations of sea surface temperature were obtained between 1200 GMT on 27 August and 0000 GMT on 17 September 1962. The term $Y = \Sigma (\theta_{n+j} - \theta_n)^2/N_j$ was computed for the values of j from one to six, and the straight line which best fits the observations is shown in Figure 1. The equation of the line was found (the regression of Y on j) and the

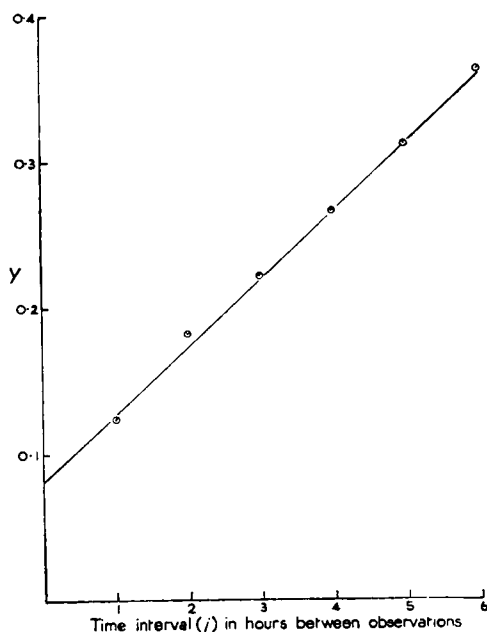


FIGURE 1—GRAPH OF Y AGAINST j

Graph of $Y = \Sigma (\theta_{n+j} - \theta_n)^2/N_j$ as a function of j .

calculated intercept on the Y -axis was 0.08166, this being the estimate of $2s^2$ (see equation (5)). Thus the standard error s of a bucket observation was found to be 0.202°F (0.112°C). The 95 per cent confidence limits of this standard error were $\pm 0.013^\circ\text{F}$ (0.007°C).

The accuracy of a bucket temperature is thus sufficient to reveal fluctuations of sea surface temperature of 1° or 2°F over periods of one or two days. Fluctuations of this magnitude do occur as can be seen in Figure 2 which shows some

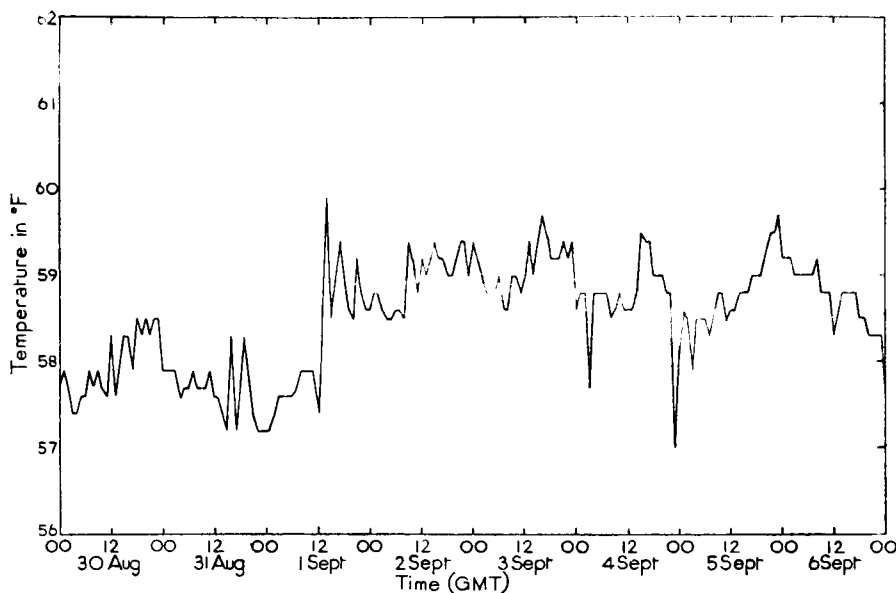


FIGURE 2—SEA SURFACE BUCKET TEMPERATURES MEASURED AT HOURLY INTERVALS BETWEEN 0000 GMT ON 30 AUGUST AND 0000 GMT ON 7 SEPTEMBER DURING VOYAGE SIX OF WEATHER SURVEYOR IN 1962

of the hourly values of sea temperature on voyage six. These fluctuations may be caused by several factors; the cloudiness, the speed, direction and fetch of the wind are a few possible causes.

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A NOTE ON EQUIVALENT TAILWINDS ON THE GREAT-CIRCLE ROUTE PRESTWICK TO MONTREAL

By R. E. S. McGAIN

Introduction.—In planning flying services on air routes there is a need for information concerning the effect of wind at the chosen flight level. The aircraft operator is primarily interested in the expected duration of the flight and thus the frequency of headwinds or tailwinds over the route is important. It has been found convenient to produce statistics in the form of equivalent headwinds (or tailwinds) over a route.^{1,2,3} The equivalent tailwind over a route may be defined formally as that wind which blowing uniformly along the track of an aircraft in a direction similar to the direction of the flight would result in the same duration of flight as required by the actual system of winds.¹

This note examines statistics of actual and forecast equivalent tailwinds (as found from routine working charts) over the great-circle route Prestwick to Montreal (2700 n.miles) at 500 mb and 300 mb during the period January 1961 to October 1963 inclusive.

Method of measurement.—From January 1961 to March 1962 inclusive the forecast charts were composite-time charts with a time difference between Prestwick and Montreal of nine hours (assuming an airspeed of 300 knots), and valid for departure from Prestwick during six-hour periods, 0000–0600 GMT, etc. From April 1962, 300 mb charts were drawn using the 1000 mb pattern combined with the 1000–300 mb thickness pattern. In the earlier period 300 mb charts had been constructed from the 500 mb contour pattern and the 500–300 mb thickness pattern.

A transparent template marked with the great-circle track was used for measuring the tailwind components. This track was divided into 10 equal sections with a pair of points marked at the mid-point of each section, the points being spaced 100 n.miles on either side of the track. This distance was chosen so that a difference in contour height of 200 feet or 60 metres between the points was equivalent to a tail component of 20 knots (chart scale being taken as constant throughout the route). When making the measurements the number of contour lines between each pair of points was counted and the sum of the 10 counts multiplied by two to give the tail component along the route. The effect of the beam component was calculated by counting the number of contour lines crossed by the great-circle track, and converting this value into a beam component (using prepared tables) and then into an equivalent tail component. This, added to the tail component, gave the equivalent tailwind (ETW).

The calculated components were plotted against date and time on a graph, the successive 'actual' values (at 0000 GMT and 1200 GMT) being joined by straight lines. The forecast values were unjoined and, with the introduction of fixed-time charts, were plotted at times corresponding to these charts.

With the earlier, composite-time charts, the time chosen for the plot was four and a half hours after assumed departure (the mid-time of the period of validity), e.g. the value calculated on the forecast chart of validity 0600–1200 GMT was plotted at 1330 GMT.

The time difference between the forecast components and the upper air data on which they were based varied between $19\frac{1}{2}$ and 26 hours. The assumption was made that the actual ETW varied during a 12-hour period so as to lie on the straight line joining successive plots and errors were calculated from these assumed values.

Frequency distribution of errors.—A positive error in the forecast values is one in which the forecast component is less than the head component or greater than the tail component calculated from actual charts. In the calculations the errors were grouped in 5-knot bands against 10-knot bands of actual ETW's. The errors arising from the method adopted are discussed by Harley⁴ on whose paper this note is based. Table I (a) and (b) shows the seasonal distribution of errors during the period, and Table II (a) and (b) shows for each season the means and standard deviations of the actual ETW's.

The mean errors in Table I are mostly small and the majority are positive, i.e. the headwind component tends to be underestimated. The values of the mean errors vary erratically except in winter at 500 mb. For the whole period the mean error at 500 mb was 0.3 with a mean standard deviation of 9.0 while the mean error at 300 mb was 0.7 with a mean standard deviation of 12.0.

TABLE I—ERRORS IN FORECAST EQUIVALENT TAILWINDS (a) AT 500 MB AND (b) AT 300 MB

Season	Year	(a)		(b)	
		Mean of errors	Standard deviation from actual <i>knots</i>	Mean of errors	Standard deviation from actual <i>knots</i>
Winter (Dec., Jan., Feb.)	1961*	0.2	11.2	1.7	12.4
	1962	0.3	10.3	-1.5	13.2
	1963	0.3	10.0	-0.1	12.8
Spring (Mar., Apr., May)	1961	-0.5	8.7	2.6	12.0
	1962	0.6	8.6	0.7	11.6
	1963	0.8	8.4	0.3	11.4
Summer (June, July, Aug.)	1961	1.3	7.9	1.4	11.6
	1962	0.1	7.1	-0.5	10.2
	1963	-0.9	7.3	0.3	9.7
Autumn (Sept., Oct., Nov.)	1961	0.9	9.3	1.1	10.8
	1962	0.6	8.3	-1.5	13.6
	1963†	2.0	9.3	1.0	15.0

*Winter 1961 refers to January and February only.

†Autumn 1963 refers to September and October only.

TABLE II—ACTUAL EQUIVALENT TAILWINDS (a) AT 500 MB AND (b) AT 300 MB

Season	Year	(a)		(b)	
		Mean ETW	Standard deviation of ETW <i>knots</i>	Mean ETW	Standard deviation of ETW <i>knots</i>
Winter (Dec., Jan., Feb.)	1961*	-23	14	-35	16
	1962	-31	24	-45	29
	1963	-22	21	-35	25
Spring (Mar., Apr., May)	1961	-15	15	-25	20
	1962	-11	23	-24	24
	1963	-20	18	-28	21
Summer (June, July, Aug.)	1961	-32	10	-46	16
	1962	-14	16	-32	20
	1963	-20	12	-30	16
Autumn (Sept., Oct., Nov.)	1961	-32	15	-43	19
	1962	-29	15	-42	20
	1963†	-39	17	-57	20

*Winter 1961 refers to January and February only.

†Autumn 1963 refers to September and October only.

At 500 mb the standard deviation of the errors from the actual is lowest in summer and highest in winter. The difference is not so marked at 300 mb although the standard deviations in spring and summer are lower generally than those in autumn and winter.

Table III shows the percentage distribution of errors at 500 mb and 300 mb for the whole period. The individual years show similar distributions.

TABLE III—PERCENTAGE DISTRIBUTION OF FORECAST ERRORS AT 500 MB AND 300 MB

		5-knot band centred on																			
		50	45	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	
		<i>per cent</i>																			
500 mb						0.2	0.7	1.8	5.2	12.4	19.8	23.9	18.2	10.8	4.3	2.0	0.6	0.1	0.1		
300 mb		0.1	0.2	0.3	1.0	2.0	4.3	7.4	11.4	15.3	19.8	15.1	10.5	6.5	3.1	1.7	0.8	0.3	0.1		

A forecast error is taken as positive when the forecast ETW is greater than actual.

The extreme errors were greater at 300 mb than at 500 mb, particularly in the case of positive errors. The largest errors (50 kt at 300 mb) occurred in September 1963 and refer to one day only. The distribution of errors can also be shown by the percentage frequency of error less than any given amount disregarding the sign of the error (see Figure 1).

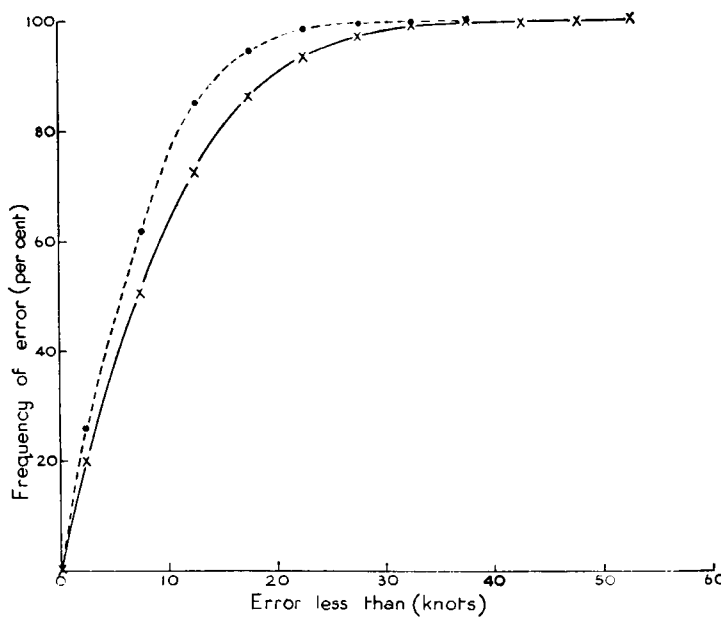


FIGURE 1—PERCENTAGE FREQUENCY OF ERRORS IN FORECAST EQUIVALENT TAILWINDS LESS THAN VARIOUS AMOUNTS
 x———x 300 mb - - - - 500 mb

Actual and forecast ETW's at both levels were correlated for 1963 and the results are shown in Table IV.

TABLE IV—CORRELATION BETWEEN ACTUAL AND FORECAST VALUES OF EQUIVALENT TAILWIND DURING 1963

Level	Mean of actuals	Standard deviation of actuals	Mean of forecasts	Standard deviation of forecasts	Correlation coefficient
		<i>knots</i>			
500 mb	-23.7	17.0	-23.5	17.3	0.88
300 mb	-34.3	22.3	-33.5	22.9	0.85

At both levels the mean of the forecasts is slightly lower than that of the actuals, while the standard deviations are slightly higher. The difference between the means of actuals and forecasts at each level for the one year of 1963, i.e. 0.2 and 0.8, can be compared with the mean errors for the whole period, 0.3 and 0.7, and are of the same sign.

The errors at 300 mb in individual 10-knot bands of actual ETW's were also examined and the results are shown in Table V.

The mean value of the 300 mb ETW was about -35 kt for the whole period and the figures in Table V suggest that forecasts tended to err in the direction of this mean value. The smaller positive or negative values of ETW are often persistent, and show less variability over a period. In Table V, between +10 and -9 knots, the mean errors are relatively large, but the standard deviations of the errors have their lowest values, corresponding to the smaller variability.

TABLE V—ERRORS IN FORECAST EQUIVALENT TAILWIND FOR VARIOUS RANGES OF

Range of ETW	ACTUAL VALUES AT 300 MB		Number of occurrences
	Mean of errors <i>knots</i>	Standard deviation of errors	
-90 to -99	16.3	13.5	15
-80 to -89	7.1	16.0	44
-70 to -79	6.7	13.5	110
-60 to -69	5.7	12.7	227
-50 to -59	2.5	11.5	333
-40 to -49	2.3	12.3	456
-30 to -39	-0.5	11.4	543
-20 to -29	-1.9	11.7	431
-10 to -19	-1.6	10.2	335
0 to -9	-2.7	10.1	199
10 to 1	-2.7	9.9	86
20 to 11	-2.9	11.4	54
30 to 21	-7.5	12.1	24

Actual equivalent tailwinds.—The actual equivalent tailwinds measured during the period January 1961 to December 1963 were investigated and mean seasonal values were included in Table I and II. Mean values at 300 mb for individual months were calculated for comparison with climatological values given in *Meteorological Reports* No. 20.³ This comparison is shown in Table VI.

TABLE VI—COMPARISON BETWEEN MEAN EQUIVALENT HEADWINDS AND STANDARD DEVIATIONS ON THE GREAT-CIRCLE ROUTE PRESTWICK TO MONTREAL AS GIVEN BY METEOROLOGICAL REPORTS NO. 20 AT 30,000 FT AND VALUES FROM 300 MB

Source of data	CHARTS DURING 1961-63				Standard deviation			
	Mean equivalent headwind							
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
<i>Met. Rep.</i> No. 20 at 30,000 ft	53	41	35	44	19	19	15	18
300 mb charts	38	18	31	48	24	21	21	22

The 300 mb values are the means for three years, and show considerable variation from the climatological values, but the differences are probably due to the short period for which data were extracted for this investigation.

The extreme values found in individual months are shown in Table VII.

TABLE VII—MONTHLY EXTREMES AND EXTREME RANGES OF EQUIVALENT TAILWIND

Month	JANUARY 1961 TO DECEMBER 1963					
	Least favourable winds		Most favourable winds		Extreme range	
	500 mb	300 mb	500 mb	300 mb	500 mb	300 mb
	<i>knots</i>		<i>knots</i>		<i>knots</i>	
January	-69	-96	+32	+33	101	129
February	-87	-108	+20	+16	107	124
March	-54	-69	+21	+25	75	94
April	-59	-89	+24	+28	83	117
May	-52	-73	+27	+29	79	102
June	-61	-77	+25	+22	86	99
July	-46	-71	+11	+24	57	95
August	-57	-89	-2	-11	55	78
September	-82	-120	+12	+7	94	127
October	-70	-104	+4	+8	74	112
November	-77	-90	+7	+7	84	97
December	-79	-96	+23	+32	102	128

At 500 mb, the greatest range of monthly extremes over the period was that of February (107 kt), although December and January also had ranges exceeding 100 kt. At 300 mb, December, January, February and September all had ranges between 124 and 129 knots. The months with positive ETW's in

each year were July and December. August, the least variable month, was the only one showing no positive ETW, but positive ETW's occurred in only one year of the three in January, September, October and November. The greatest extreme range within a single month occurred in February 1962 (124 kt).

The pattern of ETW's plotted on a day-to-day basis shows very marked variations over short time intervals, and the ETW's were therefore compounded into overlapping five-day means (pentads) to show the main changes of the

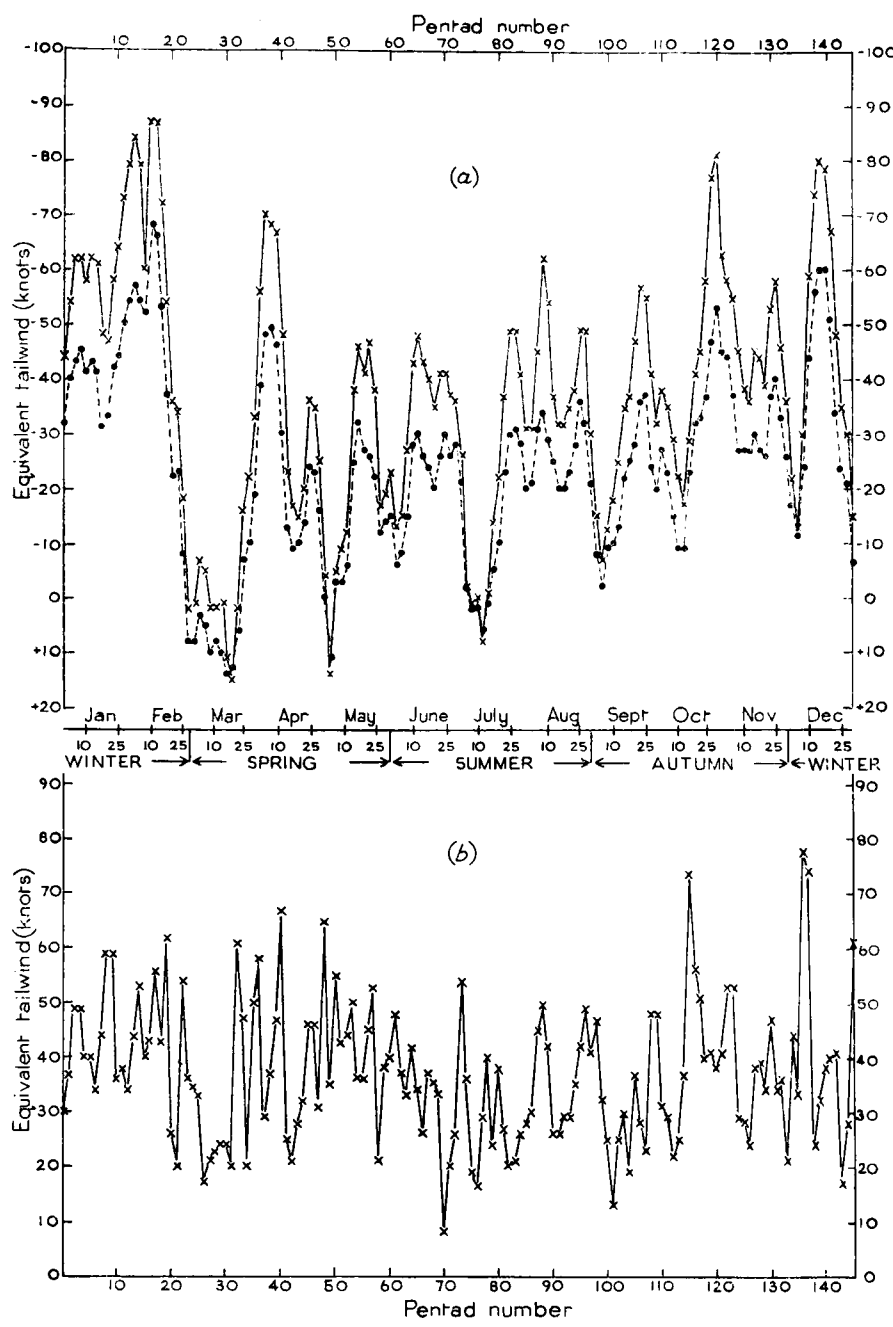


FIGURE 2—PENTADS OF EQUIVALENT TAILWINDS FOR 1962

(a) Pentads of actual ETW's.

(b) Range within each pentad.

x — x 300 mb

--- 500 mb

pattern with time. Each pentad is the mean of 10 successive actual values, No. 1 covering the period 0000 January 1 to 1200 GMT January 5, No. 3 covering the period 0000 January 6 to 1200 January 10 and so on, with overlapping pentads such as No. 2, which covers the period 1200 January 3 to 0000 January 8. This gives 145 values for each complete year and these values for both levels in 1962 are shown in Figure 2. As an indication of the variation of the ETW, the range of extreme values at 300 mb in each pentad is also shown in Figure 2. This range is the difference between the most favourable and the least favourable ETW in the pentad.

Over this period there is no consistent pattern from year to year, three years' data being insufficient to give a climatological pattern. Certain points, however, do emerge from the figure and from Tables I, II and VII. The ETW has its lowest negative mean value in the spring of each year, and spring is the only season of the year in which positive ETW's show in the pentads of each year. In each year summer has the lowest value for standard deviation of ETW and this is shown also in the low ranges of pentad extremes in the lower part of Figure 2. The extreme range of February 1962 can be seen in the pentad pattern with the steady decrease in headwind during the last fortnight of the month.

As can be seen from Figure 2 the patterns for 500 mb and 300 mb are very similar in shape and the ETW's of the two levels were correlated for the period January 1961 to June 1962. The correlation coefficient was found to be 0.94 and the regression equations are:

$$C_3 = 1.22C_5 - 7.2 \text{ knots} \quad \dots (1)$$

$$C_5 = 0.72C_3 + 2.3 \text{ knots} \quad \dots (2)$$

where C_3 denotes ETW at 300 mb and C_5 denotes ETW at 500 mb.

The ETW's are predominantly negative and the equations indicate that the ETW at 300 mb is usually less favourable than that at 500 mb. Although on individual occasions this may not be the case (as shown by the extreme values in Table VII), it generally is the case with the smoothed values of the pentads. Equation (1) can be compared with that given in WMO *Technical Note* No. 35⁵ for comparison between wind speeds at 500 mb (V_{500}) and at 300 mb (V_{300}) for three stations in America in a single month:

$$V_{300} = 1.16V_{500} + 13.5 \text{ knots.}$$

The relationship of the ETW's is shown as a correlation surface in Figure 3 with the regression lines superimposed, line A corresponding to equation (1) and line B to equation (2). X is the point given by the means at the two levels: -36 kt at 300 mb and -24 kt at 500 mb. The regression lines can be used to give an estimate of the ETW at one level when the ETW at the other level is known, e.g. if the ETW at 500 mb is -50 kt, then, using line B, the expected value at 300 mb is -73 kt. Similarly if the value at 300 mb is -90 kt, then, by using line A, the value at 500 mb is found to be -68 kt.

Conclusions.—

(i) The mean error at 500 mb for the period was 0.3 with a standard deviation from actual of 9.0 kt, the corresponding values at 300 mb were 0.7 and 12.0 kt.

(ii) The correlation coefficients between forecast and actual ETW's were 0.88 and 0.85 at 500 mb and 300 mb respectively.

(iii) The mean ETW was about -25 kt at 500 mb and about -35 kt at 300 mb.

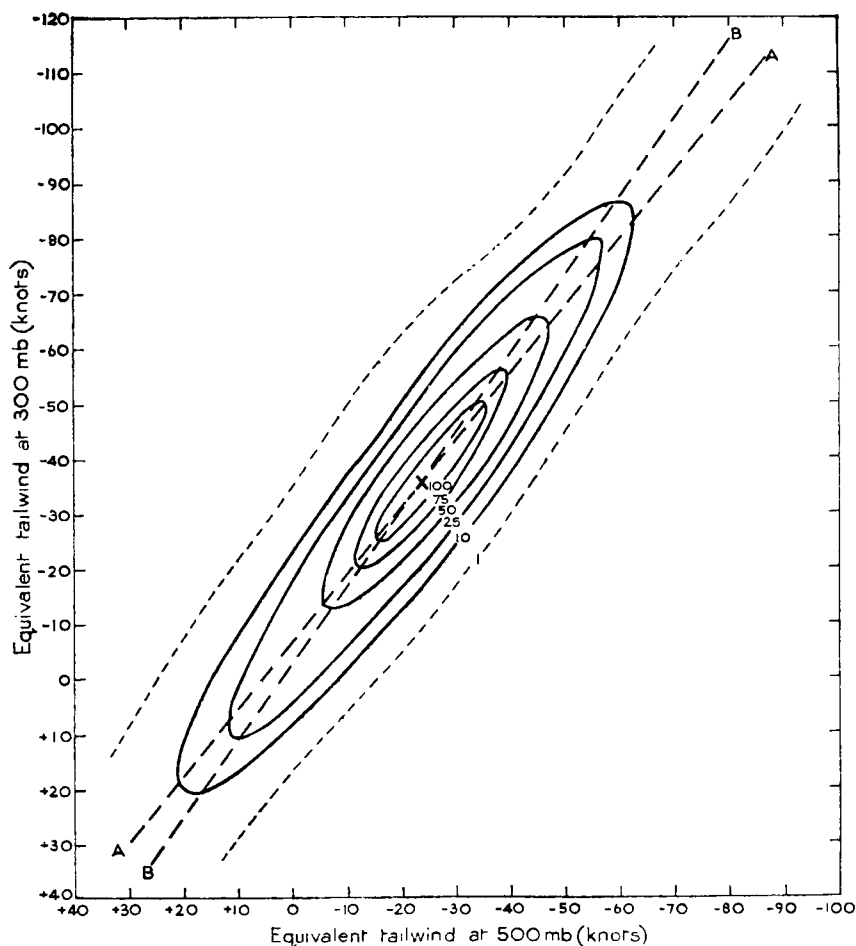


FIGURE 3—CORRELATION SURFACE OF EQUIVALENT TAILWINDS AT 500 MB WITH EQUIVALENT TAILWINDS AT 300 MB

X Mean ETW at each level.

A Regression line for 300 mb from 500 mb corresponding to equation (1).

B Regression line for 500 mb from 300 mb corresponding to equation (2).

The figure labelling each contour gives the actual number of observations contained in a cell representing 10 knots at 500 mb by 10 knots at 300 mb.

(iv) Spring was the only season in each year showing positive ETW in a five-day period.

(v) Given an ETW at either 500 mb or 300 mb, the ETW at the other level can be found simply and with a fair degree of accuracy.

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METEOROLOGICAL CONDITIONS ALLOWING A RARE OBSERVATION OF 24-MICRON SOLAR RADIATION NEAR SEA LEVEL

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Summary.—Atmospheric transmission of solar radiation of 24- μ (micron) wavelength was observed at a sea-level site in Death Valley National Monument, California, U.S.A., on 15 March 1963. The atmospheric environment which allowed this transmission is briefly described. Analysis of surface and upper air pressure-moisture patterns, and space and time cross-sections, leads to the conclusion that the observed transmission was permitted by a column of extremely dry and cold air passing over the Death Valley site during the afternoon of 15 March.

Introduction.—In support of a project designed to examine theoretically and experimentally the effects of the earth's atmosphere on the transmission of 20- μ to 40- μ solar radiation, field data were taken at 34 metres below sea level in Death Valley National Monument, California (36°30'N, 116°53'W) from 8 March 1963 to 24 March 1963. The transmission measurements were taken with a heliostat and a Perkin-Elmer Model 112U spectrophotometer. During the afternoon of 15 March, transmission of solar radiation up to 24.4 μ was observed.

The occurrence of 24.4- μ transmission, coupled with a mid-afternoon increase of transmission with increasing optical air mass, led to an analysis of the atmospheric environment which could have allowed this transmission.

Observed transmission.—The sky over Death Valley on the morning of the observation was overcast, affording little hope that the spectrometer would 'see' the sun at all that day. However, the stratocumulus clouds began to dissipate shortly after 2100 GMT (1300 Pacific Standard Time, PST). Rapid clearing ensued and by 2345 GMT (1545 PST) the sky was cloudless.

With clouds still capping the mountains to the east and west, the first transmission run, between 2130 GMT (1330 PST) and 2200 GMT (1400 PST), showed the atmosphere as presenting a window for solar radiation of 24- μ wavelength. The following transmission run, 2200 GMT (1400 PST) to 2230 GMT (1430 PST), showed an increase in transmission, though scattered clouds were still topping the surrounding peaks. In subsequent runs, the transmission diminished as expected as a result of the rapidly increasing number of optical air masses through which the radiation had to penetrate.

At the time of the aforementioned transmission runs, the transmission at 24.4 μ and its subsequent increase were attributed to dry air passing over the site. The decreased number of water molecules would thus reduce the probability of the pure rotational absorption of radiation of this wavelength by the triatomic water molecules. The surmise of dry air passing over the site was supported by three contemporaneous observations: (a) rapid clearing of the clouds, (b) the particularly deep blue hue of the sky, and (c) the mean mixing ratio at the surface during the afternoon which was about one half of the lowest mean mixing ratio observed at the site during each of the preceding four days.

Synoptic surface pattern.—To illustrate the pressure and frontal pattern existing over the Death Valley area on 14 and 15 March, a sequence of synoptic surface charts is shown in Figures 1(a)–(d). The 1500 GMT map for 14 March (Figure 1(a)) shows a cold front across the north-western corner of California. Skies over Death Valley at that time were clear, except for a trace of thin cirrus cloud. The front passed over the site that afternoon to the accompaniment of sustained 20-knot winds, blowing dust, and scattered puffs of cumulus clouds.

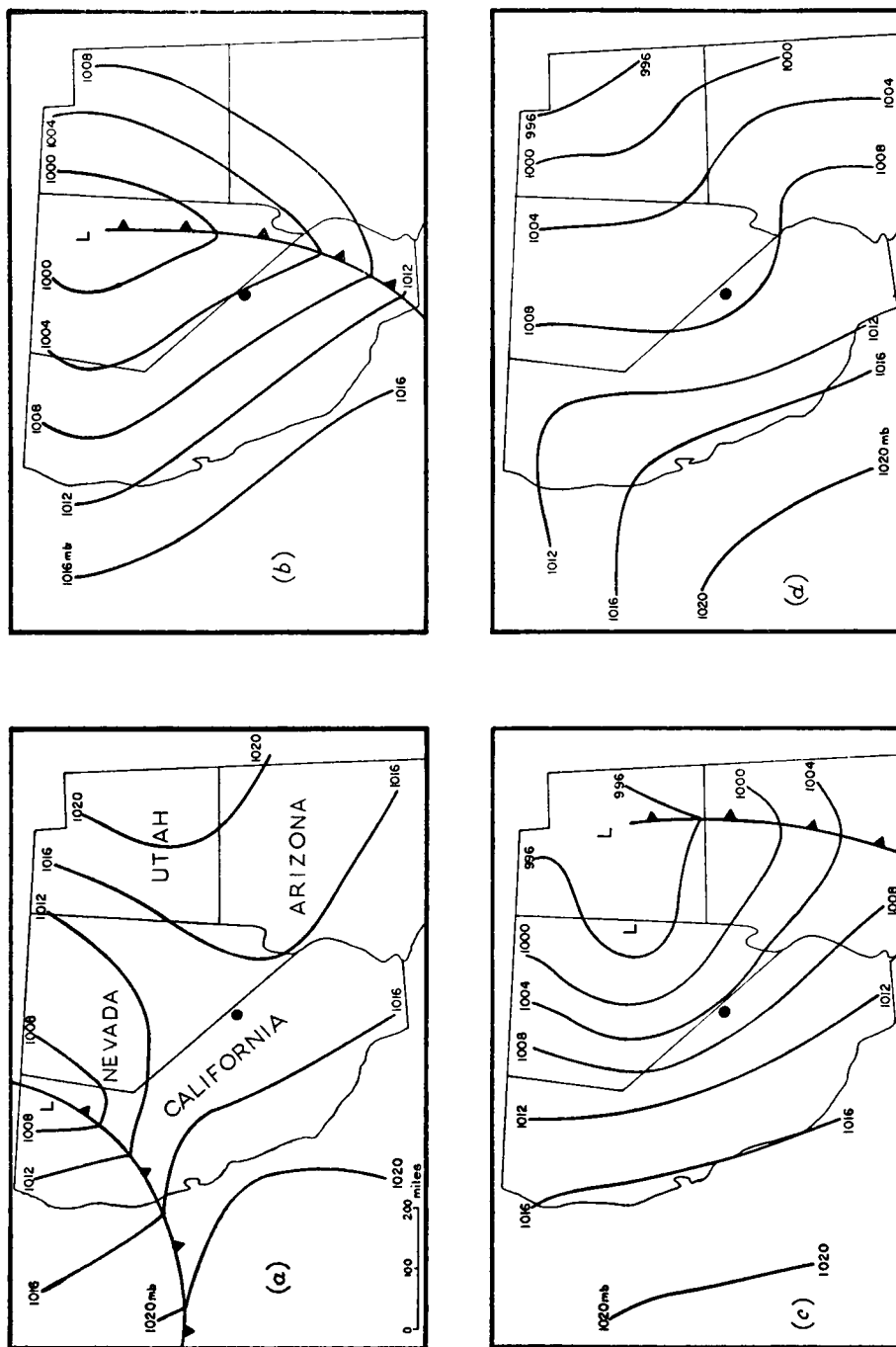


FIGURE 1—SYNOPTIC SURFACE CHARTS

(a) 1500 GMT on 14 March 1963
 (b) 0300 GMT on 15 March 1963
 (c) 1500 GMT on 15 March 1963
 (d) 0000 GMT on 16 March 1963

The state boundaries and coastline are shown as faint lines, and the four states of California, Nevada, Utah and Arizona are named in Figure 1(a). The position where the field data were taken is marked by a large dot.

By 0300 GMT, the cold front extended along a line from Ely, Nevada, through Las Vegas, Nevada, and on out over the Pacific Ocean across San Diego (Figure 1(b)). (Note the secondary trough oriented east-west across northern Nevada and California.) By sunrise on 15 March, the surface cold front had progressed to central Arizona and the secondary trough to central Nevada (Figure 1(c)). By the afternoon of interest, the front had moved out of the four-state area (Figure 1(d)) and the secondary trough to a position directly over Death Valley.

Upper air.—Analysis of relevant upper air data substantiated the original conclusion that a pronounced drying of the atmosphere had occurred over the site on the afternoon of 15 March. Examination of the 500 millibar surface, as analysed in Figures 2(a), (b) reveals a pocket of dry air situated to the west of the Death Valley site at 1200 GMT (Figure 2(a)). Twelve hours later, the same pocket was centred over the site (Figure 2(b)), which corresponds well with the peak transmission observed at 2215 GMT.

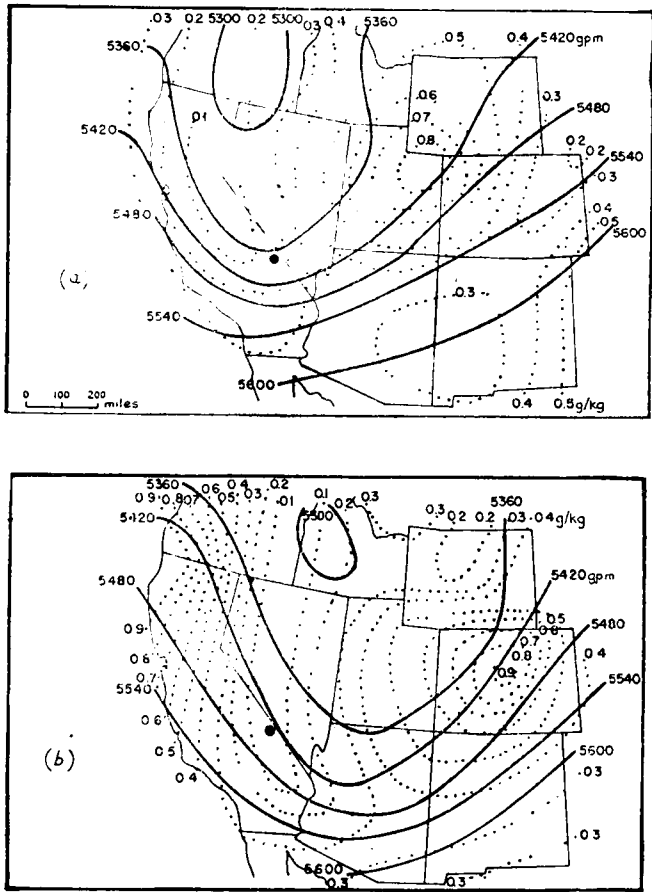


FIGURE 2—500 MILLIBAR ANALYSES

(a) 1200 GMT on 15 March 1963 (b) 0000 GMT on 16 March 1963
 — 500 mb contours (gpm), mixing ratio (g/kg).

The state boundaries and coastline are shown as faint lines, and the four states of California, Nevada, Utah and Arizona are named in Figure 1(a) (see page 78). The position where the field data were taken is marked by a large dot.

Vertical cross-sections of potential temperature and mixing ratio revealed an eastward progressing, dry, cold column of air. Figure 3 shows the vertical cross-section near the time of observed maximum transmission.

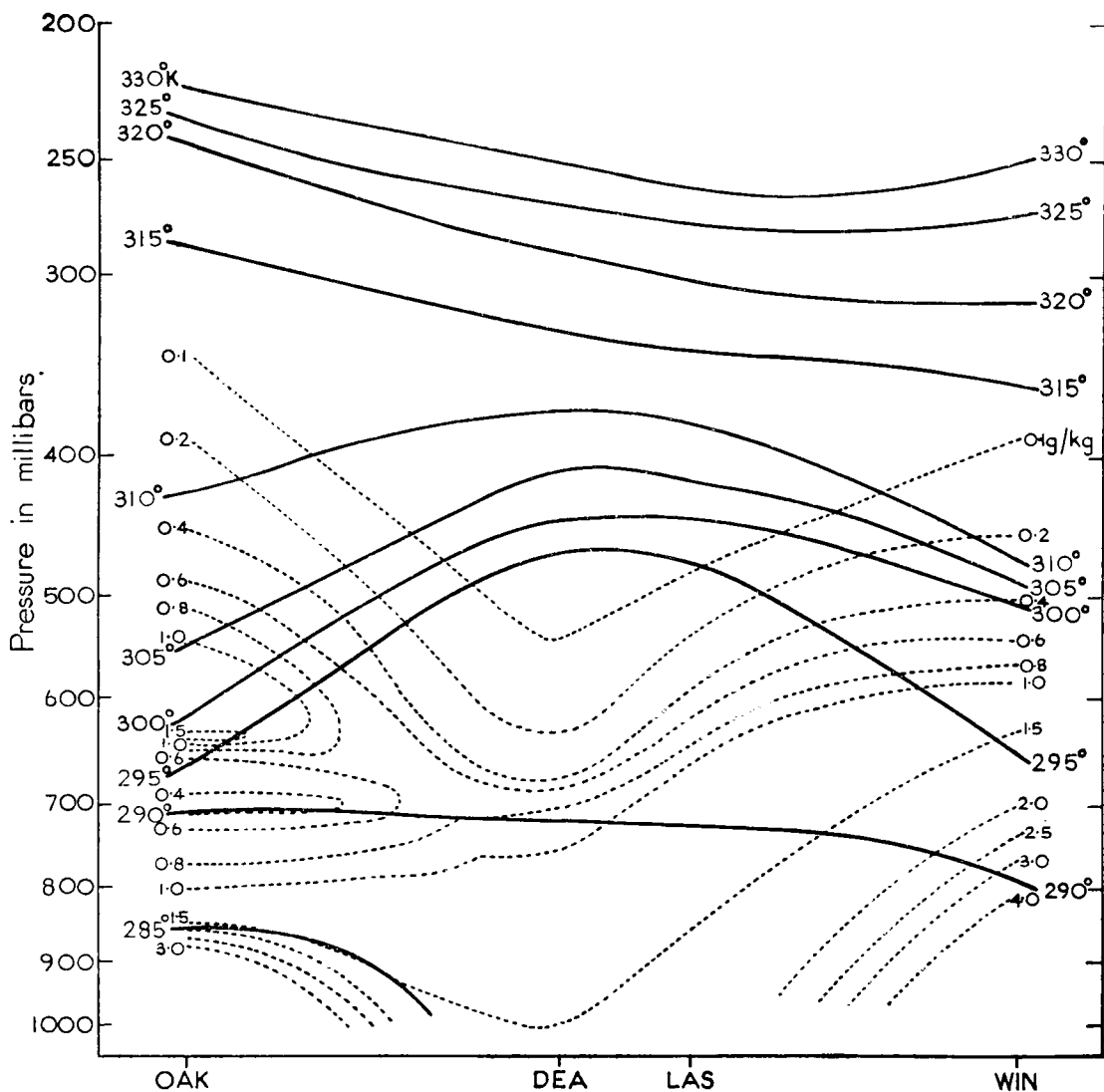


FIGURE 3—VERTICAL CROSS-SECTION OF POTENTIAL TEMPERATURE AND MIXING RATIO FROM OAKLAND, CALIFORNIA, TO WINSLOW, ARIZONA, AT 0000 GMT ON 16 MARCH 1963

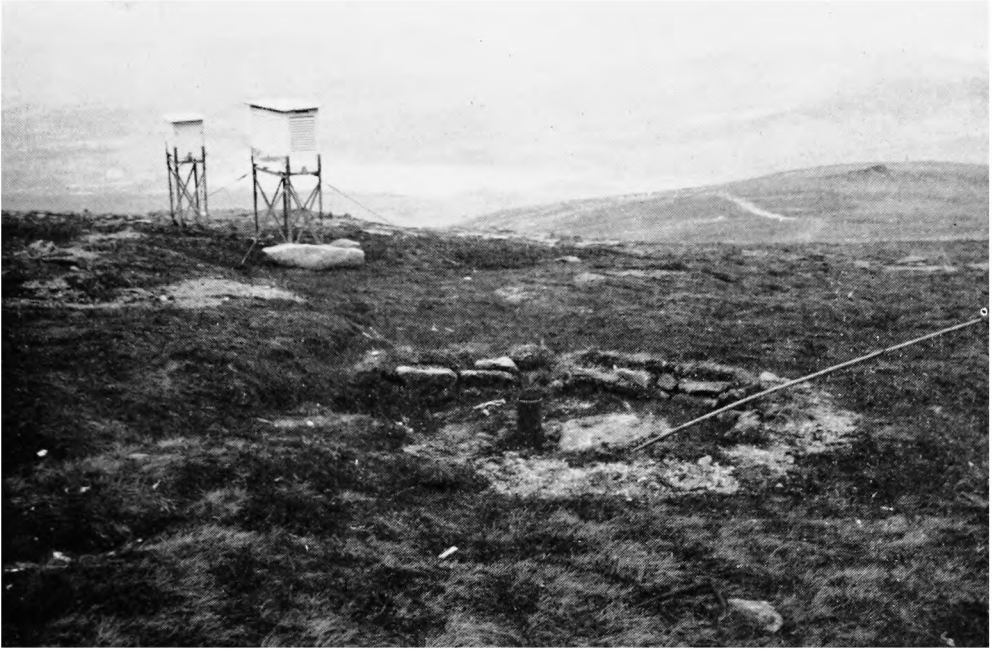
———— Potential temperature (°K), mixing ratio (g/kg).

OAK = Oakland, California, (6m above MSL), DEA = Death Valley, California, (34 m below MSL), LAS = Las Vegas, Nevada, (664m above MSL), WIN = Winslow, Arizona, (1505 m above MSL). Oakland is about 660miles from Winslow.

The cross-section is drawn in an approximate west-north-west to east-south-east direction.

Conclusion.—The resultant picture is of a column of very dry air, extending from a surface secondary trough to 350 millibars, moving across the Death Valley site during the afternoon of the 15th. The initial break-up of the clouds signalled the passage of the surface trough over the site. The influx of drier air continued until mid-afternoon when the peak transmission of 24.4μ was observed.

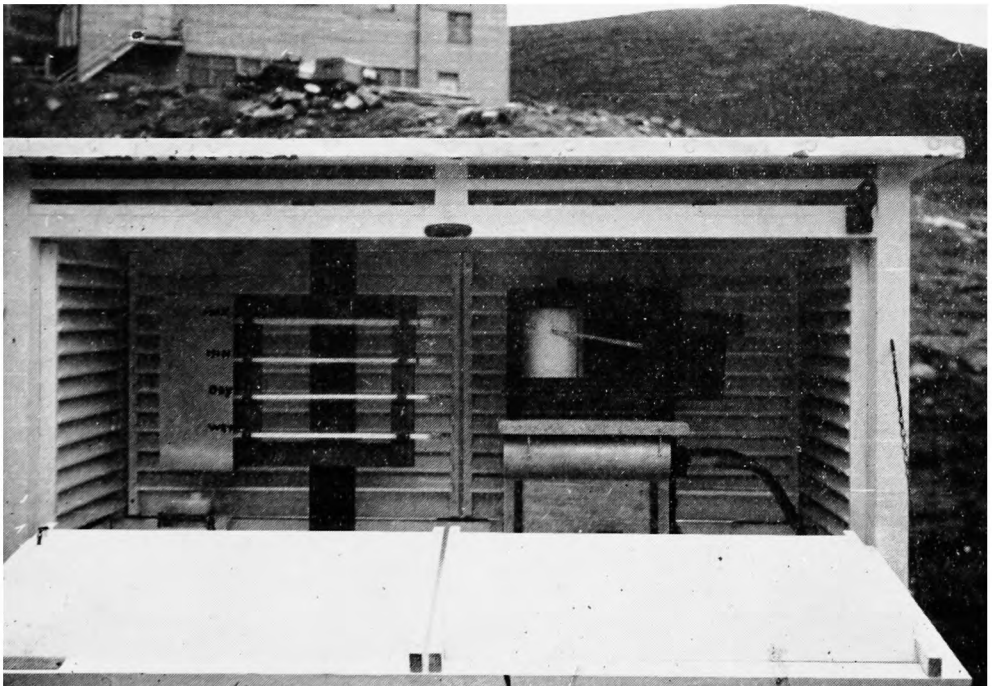
Thus, on occasion, the earth's atmosphere is dry enough to allow solar radiation up to at least 24μ to reach sea level, even at latitudes as low as 36°N .



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PLATE I—THERMOMETER SCREENS AND RAIN-GAUGE AT THE CAIRNGORM STATION

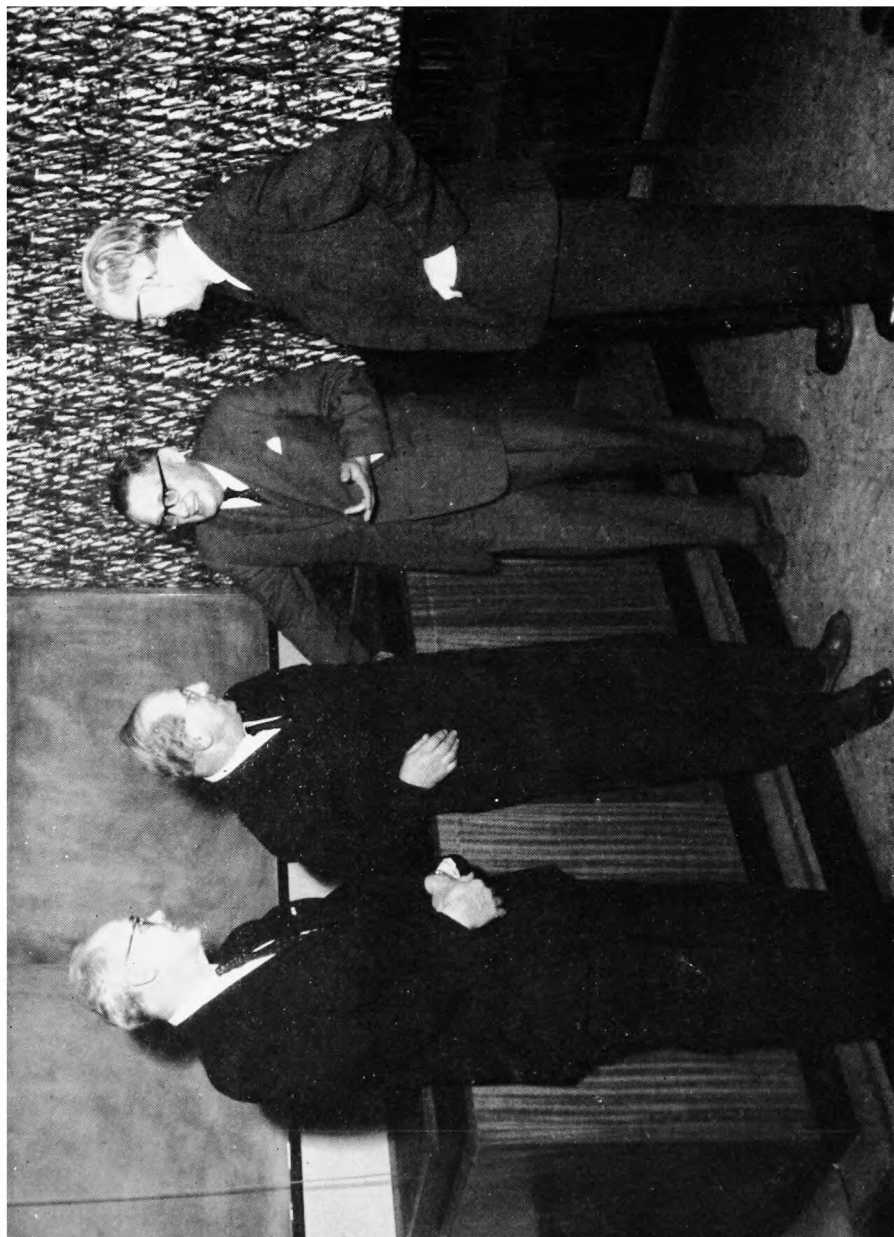
The cane in the foreground is placed vertically in the ground when snow is lying to indicate to skiers the position of the rain-gauge (see page 84).



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PLATE II—INSTRUMENTS IN THE THERMOMETER SCREEN AT COIRE CAS SHIELING STATION

The hair hygrometer can be seen on the right-hand side above the mercury-in-steel thermometer (see page 84).

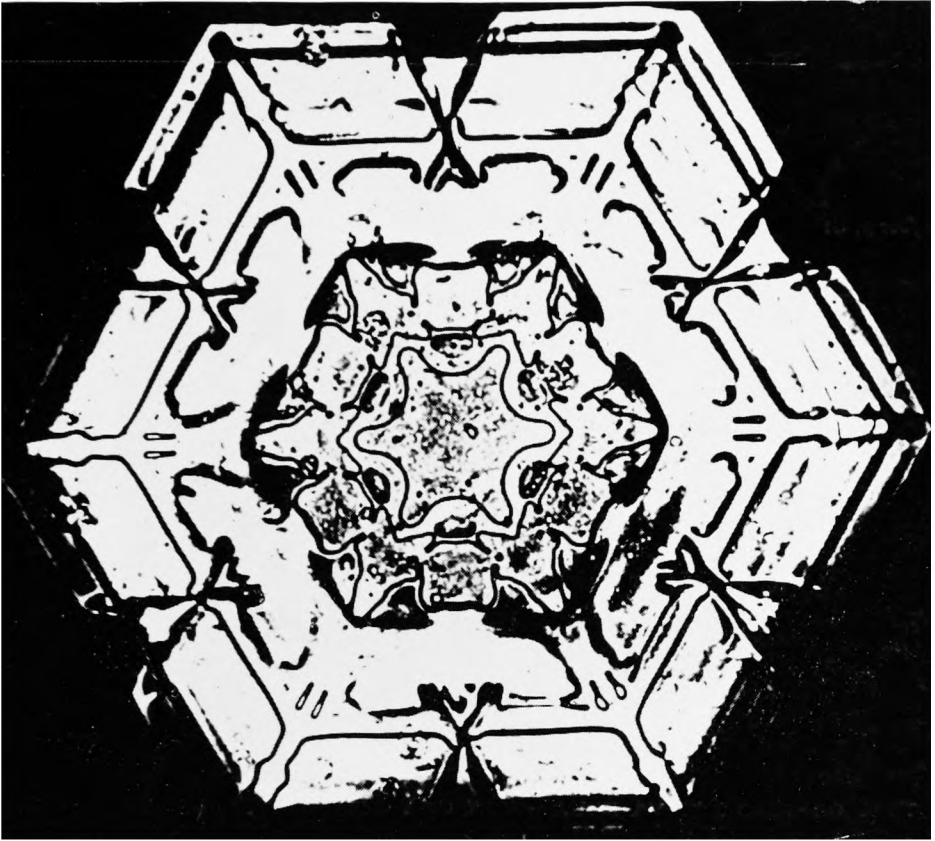


Crown copyright

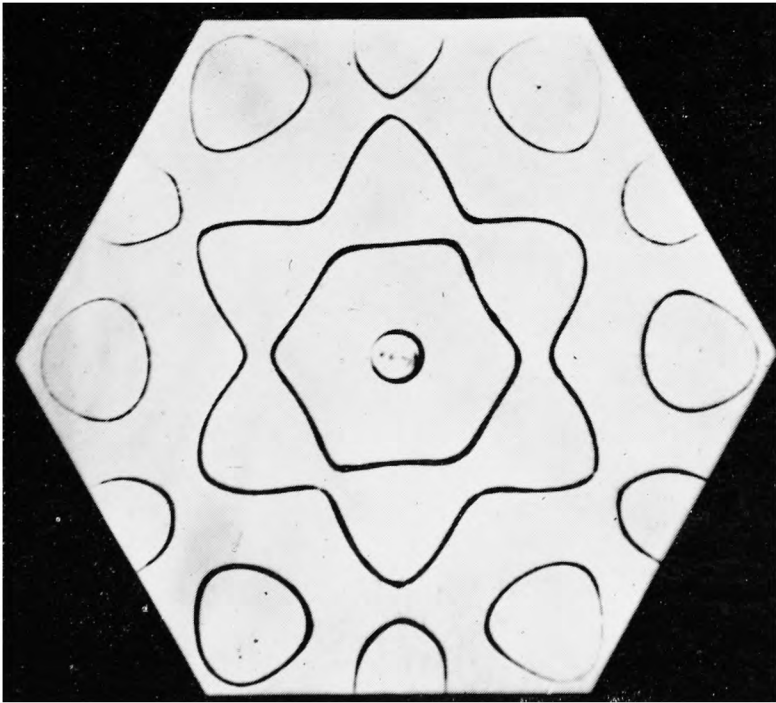
PLATE II—THE DIRECTOR-GENERAL TALKING TO PROFESSOR TOLANSKY BEFORE

THE LECTURE AT BRACKNELL ON 19 NOVEMBER 1964

Left to right: Dr. R. C. Sutcliffe, F.R.S., Professor S. Tolansky, F.R.S., the Director-General, Sir Graham Sutton, F.R.S., and Dr. A. C. Best (see page 94).



Photograph by courtesy of McGraw-Hill Publishing Co. Ltd.
(a)



Photograph by Professor S. Tolansky, F.R.S.

(b)

PLATE IV—PHOTOGRAPHS OF AN ICE CRYSTAL (a) AND A VIBRATING PLATE (b)
DEMONSTRATING FINE-SCALE CURVILINEAR SYMMETRY

See page 95.

To face p. 81



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PLATE V—NEW METEOROLOGICAL OFFICE WIND-FINDING RADAR AT
CRAWLEY

Dr. R. C. Sutcliffe, F.R.S., is seen talking to Mr. P. R. Max, General Manager of the Radar
Division of Cossor Electronics Ltd. (see page 95).

THE INCIDENCE OF LOW RELATIVE HUMIDITY IN THE BRITISH ISLES

By F. H. W. GREEN
The Nature Conservancy

Introduction.—It has become clear that occasions of relative humidity below 20 per cent are not nearly as rare in the British Isles as would appear from references in earlier meteorological literature. Hawke,^{1,2} in particular, drew attention to the incidence of low humidity and subsequent references include notes by Needham,³ Green^{4,5,6} and Smith.⁷ Since both low relative humidity and violent changes in humidity are detrimental to plants and animals, it was felt that a preliminary survey of recent occurrences would be useful.

Achnagoichan autographic readings.—Since May 1956 a thermohygrograph has been functioning most of the time in a standard screen at Achnagoichan (1000 ft above MSL) in Strathspey. The records of this instrument from May 1956 to October 1964 were used as a rough guide to the number of days of very low humidity during this period and an analysis is shown in Table I. The number of days when the record showed a relative humidity of 30 per cent or less was 109 with a large monthly frequency in April, May and June. There were 10 days with humidity below 20 per cent and 2 below 10 per cent.

TABLE I—MONTHLY FREQUENCY OF DAYS OF LOW HUMIDITY AT ACHNAGOICHAN,
MAY 1956–OCTOBER 1964

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
30 per cent and below	1	6	7	15	26	29	5	8	5	4	0	3	109
20 per cent and below	0	2	1	2	3	1	1	0	0	0	0	0	10
10 per cent and below	0	0	0	0	0	2	0	0	0	0	0	0	2
Cases unrelated to diurnal rise in temperature	0	2	4	0	0	1	0	0	1	2	0	3	13

The totals for individual years would be misleading, owing to interruptions, but 1959 had by far the greatest number of days (32) with relative humidity below 30 per cent.

The great majority of the occasions were days of warm, dry weather with clear skies, when the diurnal temperature range was considerable, and the fall in humidity corresponded with the daily rise in temperature. On a few occasions, mostly in winter and early spring, the low humidity was not readily correlated with a diurnal rise in temperature.

Discussion of particular occasions.—A special examination was made of a few of the more important occasions, including some which were not indicated by the Achnagoichan hygrograph, but mainly those where the Achnagoichan humidity was below 20 per cent or was not readily correlated with a diurnal rise in temperature.

March 1959.—On 1 March 1959, the hygrograph trace at Achnagoichan went down well below 20 per cent a little before midday. The fall did correspond to some extent with a rise in temperature, but it had begun before the rise started, and in fact the temperature fell about 4°F at one stage during the fall in humidity. Relative humidity had been fairly low since 24 February,

since when both it and the temperature had shown considerable short-period oscillations, although the total range of temperature over the period barely exceeded 10°F.

During this period there were strong south-westerly winds and a series of depressions moved in a north-eastward direction, with several associated fronts crossing the British Isles. The contrast between the air-mass characteristics on each side of the fronts was not very great. After the passage of a front on 28 February the gradient slackened considerably and by the morning of 1 March winds were light and variable over most of Britain. Pressure was high over central Europe. Inspection of the *Daily Weather Report** (*DWR*) revealed no records of particularly low humidities, the lowest noted in fact being at Malin Head and Wick at 1200 GMT where the humidities were just above 60 per cent.

June 1959.—June 21, 1959, was one day of a series of warm, sunny days, remarkable only in that the relative humidity recorded on the hygrograph fell as low as 10 per cent, with a temperature of 70°F. The accuracy of the hygrograph at this time may be doubted, but there can be no doubt at all that the relative humidity did reach an unusually low level, and that it rose to 84 per cent between about 1500 GMT on 21 June and 0300 GMT on 22 June. In the *DWR* however only Renfrew (21 per cent) and Prestwick (31 per cent) at 1200, and Silloth (36 per cent) at 1800 had unusually low humidities. The airflow was from the south-east, and these stations were in the lee of hills. There was an anticyclone over Scandinavia, as Hawke¹ found to be usual in cases of low humidity, and pressure was low to the west of the British Isles with a front moving in from the Atlantic.

October 1959.—In the week commencing 5 October 1959, there was fine sunny weather with considerable diurnal temperature range and corresponding humidity variation. During the night of 9–10 October however, the temperature fell only a few degrees, but the humidity fell instead of rising and continued to fall to a minimum of 20 per cent at about 1500 GMT on the 10th while at the same time the temperature was rising. The only remarkably low humidities noted at *DWR* stations occurred at 1200 GMT on the 9th and were as follows:

Kew	30 per cent	Ross-on-Wye	36 per cent
Gatwick	31 per cent	Manchester	29 per cent
London (Heathrow) Airport			
30 per cent			

Again there was a south-westerly airstream between an anticyclone and a depression.

May 1960.—In the week commencing 9 May 1960, there was a centre of high pressure over the Norwegian coast and a depression to the south-west of Ireland. On the 1200 GMT chart for 12 May, a trough on an instability line was shown lying across England and Ireland from south-east to north-west. Some fairly low humidities occurred north-east of this trough, where the isobars could locally have been divergent, but no *DWR* station showed any unusual humidity that day, whereas Achnagoichan had a relative humidity of less than 40 per cent over most of the period from 0900 on the 12th to 1600 on the 13th, after which the humidity rose very steeply indeed, presumably with the passage of the trough.

*London, Meteorological Office. *Daily Weather Report*. Relative humidities for *DWR* stations were calculated from the temperatures and dew-points which are given in whole figures.

Among the *DWR* stations, only Prestwick revealed a relative humidity below 40 per cent, 38 per cent being recorded at 1200 GMT on the 11th. The Achnagoichan records showed a very remarkable drop in humidity for about two hours between about midnight and 0200 on the 11th. The humidity fell suddenly from 80 to 40 per cent and equally suddenly climbed again, possibly suggesting the presence of a layer of subsiding air: the thermograph trace was slowly falling at the time.

March 1961.—At the beginning of March 1961 an anticyclone was centred over the north of France with a complex low-pressure system to the north and north-west of the British Isles. The pressure gradient was steepest between the Faeroes and the south of Scotland. The Achnagoichan hygrograph trace moved erratically, and often quite out of phase with the thermograph, the lowest relative humidity reading being about 26 per cent during the afternoon of 5 March. Among the *DWR* stations however, a really noteworthy low humidity was observed only at Boscombe Down, where the dew-point was 21°F and relative humidity 28 per cent.

February 1962.—On several days running in the week commencing 19 February 1962, there were fine sunny conditions and on 22 February the reading of the Achnagoichan hygrograph dropped to 20 per cent. No remarkably low humidities occurred at any of the *DWR* stations during this period of easterly airflow between a Scandinavian anticyclone and a depression just west of Portugal. As would be expected, humidities were lower inland and on the west coast, but none were as low as 40 per cent.

March 1962.—On 7 March 1962 there were strong south-south-easterly winds between an anticyclone over north Germany and a deep complex depression west of the British Isles. Relative humidity at Achnagoichan fell during the morning from over 70 per cent to less than 30. This was in itself not very unusual, but the slow rise that followed was rather remarkable—humidity only began to climb quickly at about 0800 GMT the next morning, reaching over 80 per cent by midday on the 8th. Inspection of the *DWR* revealed the following occurrences of relative humidity of 40 per cent or below:

1200 GMT on 7 March, Valley	35 per cent
1800 GMT on 7 March, Hurn	35 per cent
1800 GMT on 7 March, Aberporth	35 per cent
1800 GMT on 7 March, Ross-on-Wye	31 per cent
1800 GMT on 7 March, Benbecula	34 per cent
0000 GMT on 8 March, Heathrow	34 per cent

The tendency for low relative humidities to occur in lee situations was evident, but the occurrences at Hurn and Benbecula were rather surprising.

December 1962.—The very remarkable case of 3 and 5 December 1962 has been recorded in the *Meteorological Magazine*.⁸ The instrumental records show that at least in several places in the Cairngorm region, and on the Westmorland Fells at Moor House, the air must have been very nearly 'bone dry'. Since it was quite cold at the time, a number of very low dew-points were recorded. It is worth noting that since daily instrumental records were begun at Moor House in 1952 only once before had anything really comparable occurred. This was in March 1953 and the occurrence was described by Green.⁴

February and March 1963.—After the extremely cold spell of the winter of 1962–63 came to an end in the last days of February, there was a week in which unusually low humidities occurred in many parts of the British Isles. As

shown by the Achnagoichan hygrograph, humidity fell well below 50 per cent during the morning of 26 February and did not rise above 70 per cent until 3 March. Mr. and Mrs. R. M. Murray, who run the climatological station at Prabost, Isle of Skye, drew attention to the reading of 12 per cent from their instruments at about noon on 28 February. The daily reports (0000, 0600, 1200, 1800 GMT) of all 55 stations in the *DWR* were then examined and it was found that several cases of low humidity occurred during the period 0600 February 26 to 0000 March 3.

TABLE II—NUMBER OF OCCURRENCES OF LOW RELATIVE HUMIDITY AT *DWR* STATIONS BETWEEN 0600 GMT 26 FEBRUARY AND 0000 GMT 3 MARCH 1963

	Time (GMT)	40 per cent or below	20 per cent or below		Time (GMT)	40 per cent or below	20 per cent or below
26 Feb.	0600	2	0	1 Mar.	0000	2	1
	1200	9	2		0600	1	0
	1800	2	1		1200	9	1
27 Feb.	0000	0	0	2 Mar.	1800	1	1
	0600	2	0		0000	0	0
	1200	8	2		0600	0	0
28 Feb.	1800	4	0	3 Mar.	1200	6	1
	0000	2	1		1800	2	0
	0600	1	1		0000	1	0
	1200	6	1				
	1800	3	0				

The *DWR* stations which exhibited relative humidities of 40 per cent or below, and the number of occurrences, at the four standard observation times over this period were as follows:

Cape Wrath	15	Stornoway	3
Aberporth	7	Kew	3
Carlisle	6	Eskdalemuir	2
Manchester	5	Squires Gate	2
Prestwick	5	Chivenor	2
Renfrew	4	Elmdon	1
Valley	4	Heathrow	1

The distribution of these places and occurrences is interesting. Three-quarters of the occurrences were at stations in the lee of hills in the south-south-easterly airstream, and most of the remainder were at urban sites. A few of the climatological station observations made at 0900 GMT were investigated and showed the same pattern.

September 1963.—At Achnagoichan, the occurrence of low humidity on 15 September 1963 looked at first sight like a simple case associated with diurnal rise in temperature, but closer inspection showed that the humidity fell rapidly about two hours before the temperature began to rise. The traces from the mercury-in-steel thermograph at the newly-established stations of Cairngorm (Plate I) and Coire Cas Shieling (Plate II) (3575 ft and 2500 ft above MSL respectively) confirmed this and showed that the significant change there began at about midnight. The 0900 GMT readings at Coire Cas were:

Dry bulb	Wet bulb	Vapour pressure	Relative humidity	Dew-point
63.9°F	45.6°F	2.3 mb	11 per cent	9°F

The autographic records indicate that this humidity was the lowest reached and suggest that the relative humidity was as low as 17 per cent at 0200 GMT. A sharp rise in humidity began about 1100 GMT; this was shortly before the time

when it had first begun to drop steeply at Achnagoichan. The Cairngorm thermogram trace agreed closely with that at Coire Cas, the lowest humidities being approximately as follows:

Time (GMT)	Dry bulb	Wet bulb	Vapour pressure	Relative humidity	Dew-point
0500	54°F	38.5°F	1.0 mb	7 per cent	-8°F
0900	59°F	42°F	1.5 mb	9 per cent	0°F
1215	56°F	40°F	1.3 mb	8 per cent	-3°F

A study of the *DWR* revealed widespread low humidities from the 13th to the 17th, but nothing remarkable. The only cases of relative humidity below 40 per cent were at Dyce at 1200 GMT on the 13th with 38 per cent and at Tynemouth at 1800 GMT on the 15th with 37 per cent.

Through most of the period exhibiting these very low humidities, depressions were passing from west to east, to the north of Scotland and pressure was high to the south with a notably slack pressure gradient in between. Some of the low humidities occurred within this area of nearly calm conditions, and under cloudless skies, but in the north and east of Scotland on 15 September surface winds were fairly strong.

Notable stratification in the upper air over Scotland was indicated by the cloud structure. The 1130 GMT radiosonde ascent from Shanwell showed marked stratification in the same air mass, and showed in particular a very dry layer, with relative humidity about 23 per cent at 850 mb, corresponding roughly with the height of Cairngorm. The wind direction was between about 240° and 260° at all levels, and the speed only varied between about 40 and 50 kt up to the tropopause, which was a double one above Shanwell. At the Coire Cas Shielling the surface wind at 0900 GMT was estimated as Beaufort force 5 (about 18 kt).

The *Daily Aerological Record* shows that a layer (or layers) of low humidity extended from Ocean Weather Station J (52°30'N 20°W) eastwards right across the British Isles.

This particular occurrence of low humidity therefore seems to have been associated with a very stable air mass in which there had presumably been considerable subsidence. The episode came to an end with the passage southwards over the country of a front.

January 1964.—On 18 January 1964, the synoptic situation was again that of a very pronounced anticyclone over Scandinavia, with a deep depression west of the British Isles. The isobars were divergent over Scotland. At the Coire Cas Shielling (approximately 2500 ft above MSL), according to traces on the mercury-in-steel thermograph, the humidity began to fall during the afternoon of 17 January, and gradually reached its lowest at about 0900 GMT on the 18th. It remained at about this level until mid-afternoon, after which it gradually increased and then steadied at about 83 per cent by approximately 2100 GMT. At 0900 GMT on the 18th the dry-bulb thermometer read 48.1°F and the wet-bulb 36.1°F. A comparison of the humidities according to these two readings and to the (uncorrected) thermogram trace is as follows:

	Dry bulb	Wet bulb	Vapour pressure	Relative humidity	Dew-point
Thermometers	48.1°F	36.1°F	1.8 mb	16 per cent	4°F
Thermograph	47.0°F	34.5°F	1.2 mb	11 per cent	-5°F

At Achnagoichan (about 6 miles to the west-north-west of Coire Cas and only 1000 ft above MSL) the hygrograph and thermograph agreed well with the thermometer readings at 0900 GMT. The humidity values can therefore be quoted with reasonable accuracy in the table below, which shows that the lowest hygrograph reading of 30 per cent occurred at 1100 GMT:

	Time (GMT)	Dry bulb	Wet bulb	Vapour pressure	Relative humidity	Dew-point
Achnagoichan	0900	37.7°F	31.5°F	3.5 mb	45 per cent	18°F
	1100	40°F	32°F	2.4 mb	30 per cent	12°F

Inspection of the 0900 GMT readings on 18 January at various other stations in the vicinity revealed only Glenmore Lodge with a relative humidity as low as 40 per cent, and a dew-point of 5°F, but the hygrograph trace went down to 12 per cent about 1400 GMT—having been as low as 29 per cent at 1500 on the previous day with a rise to not more than 65 per cent in between. Hourly readings at Kinloss showed humidities of 40 per cent or below at 1400, 1500, 1600, 1800 and 1900 GMT. Three-hourly readings at Cape Wrath revealed 40 per cent or less from 0000 to 1800 GMT. The low humidities at Cape Wrath had begun during the night of 16–17th and the very low reading of 12 per cent and dew-point –0.4°F was recorded at 1200 GMT on the 17th. There was a calm with a clear sky nearly all the time.

A study of the six-hourly readings of the *DWR* stations revealed no other occurrences of relative humidity 40 per cent or less.

March 1964.—This occasion characterized by low, but not remarkably low, humidities was distinguished by its striking effects on pine foliage and certain other phenomena. There were southerly winds almost continuously at gale force for nearly a week from 14 March. The winds were accompanied intermittently by snowfall sufficient to cause heavy drifting in Perthshire and parts of Strathspey. With air temperature above freezing-point and wet-bulb temperature below, a good deal of freezing was caused during the process of evaporation. Ice formed where water drained over rocks although the air temperatures were above freezing-point, and there were remarkable ‘trailers’ of frozen snow on the lee side of trees and other obstructions. A little later on, the browning of the needles on the windward sides of pine trees became most conspicuous; isolated trees were completely browned on this side as were the corresponding sides of tree crowns protruding from dense stands and plantations. It is considered that this was a desiccating effect caused by simultaneous transpiration and freezing; cell destruction may have aggravated the damage.

October 1964.—Finally a striking case recorded at the Coire Cas Shielling and Cairngorm on 4 October 1964 must be mentioned. Hair hygrograph charts at both stations recorded a fall to 8 per cent humidity. The sequence of events was as follows.

Humidity began to fall suddenly at both stations just before 0000 GMT on the 4th and there were violent fluctuations between about 60 and 80 per cent for the next two hours. After this the humidity at the upper station (Cairngorm) showed a steady but rapid fall to about 20 per cent by 0400 GMT on the 4th, and a slower, fairly steady fall after that to the minimum of just under 8 per cent soon after 1000 GMT. The humidity at the lower station (Shielling) showed a very similar trace, except that two or three violent fluctuations occurred on the descending curve; the minimum of 8 per cent was reached at 1000 GMT. At

the lower station, humidity rose quickly after this to about 30 per cent, at which level it remained, with minor fluctuations, until about 2300. Then there was a fairly rapid rise to about 90 per cent by 0300 GMT on the 5th. At the upper station the rise was more gradual, until about 0000 GMT on the 5th, after which it rose at the same time and rate as at the lower station. The accuracy of the hygrograph at the Shieling was confirmed by the mercury-in-steel thermograph trace and by the dry-bulb (54.1°F) and wet-bulb (39.9°F) temperatures read at 0930 GMT on the 4th which gave a relative humidity of 14 per cent—almost exactly as shown on the hygrograph at that time.

The synoptic situation was again a south-easterly airstream, with an elongated anticyclone stretching north-west and south-east from a centre over the western Baltic, but no humidities in the least remarkable were recorded that day at *DWR* stations or even on the hygrograph at Achnagoichan, only a few miles away. Subsidence thus seemed to affect the surface air conditions only on high ground.

Conclusions.—An examination of all the occurrences of low humidity here discussed shows that in the majority of cases the most noteworthy low humidities were recorded in the lee of hills, and most of the remainder tended to be at the places furthest away from the upwind coast. Achnagoichan is a good 'indicator station' because it is both inland and surrounded by hills on all sides. A few stations, such as Manchester, regularly reporting low humidity are in urban 'heat islands'.

The small number of reported occurrences at high-level stations is almost entirely due to the absence of such stations from the *DWR*, but the records from Moor House, Cairngorm and other high-altitude stations indicate that these are at least as susceptible to low humidities as are lee stations, to the extent that one may reasonably conclude that really exceptional widespread low humidities occur when large-scale subsidence and föhn effects coincide. Diurnal heating often plays a part in summer occasions, but only in enhancing these effects.

The records from the new Cairngorm and Coire Cas stations show that low humidities must frequently occur at high level when they do not occur at lower stations. Thus in the autumn of 1964, there was not only the occurrence on 4 October, but the relative humidity fell to 18 per cent about 2300 GMT on the night of 23–24 September, and to 20 per cent about the same time on the night of 21–22 October. There was also a sudden short-lived drop to 36 per cent about 0600 GMT on 6 October. At no other place have remarkably low humidities been noticed on these dates.

From the ecological point of view, the most significant occasions are when the freezing threshold is involved. With air temperature above freezing-point and wet-bulb temperatures below, ice can be formed as evaporation takes place and vegetation can be frost damaged. The evidence suggests that high-level and lee sites are most susceptible to this damage which occurs mainly in the month of March. The effect of soil temperatures being below freezing-point is comparable to that of wet-bulb temperatures below freezing, and it has been noted that heather 'frosting' is correlated with high daytime evaporation coinciding with freezing temperatures in the root zone.

Hawke¹ pointed out that the lowest humidities tend to occur, not in summer, but in spring and that the most usual synoptic conditions at the time is high

pressure over Scandinavia; the present investigation amply supports his contention, although it demonstrates that there are exceptions to this rule.

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551.501.71:551.510.41:551.510.534:061.3

THE OZONE SYMPOSIUM AT ALBUQUERQUE—1964

The International Ozone Commission (a Commission of the International Association of Meteorology and Atmospheric Physics) holds a symposium every two or three years, traditionally at a place where important work on ozone is being carried out. This year the Commission were the guests of the University of New Mexico, at Albuquerque—the home of Professor V. Regener, and the birthplace of the chemiluminescent ozonesonde.

Most of the participants came from the North American continent but there were also meteorologists present from Australia, France, Germany, India, Japan, Norway, Sweden and the United Kingdom. It was a hard-working week, with no 'time-off' during 'working hours'; but there was, inevitably, a 'banquet'; there was also a pleasant evening excursion for dinner at 10,000 ft on the top of a nearby mountain (Albuquerque itself is at 6000 ft) and a most enjoyable all-day excursion on the Saturday.

During the symposium some 60 papers were read with, on the whole, adequate time for discussion. The following notes do not pretend to be comprehensive.

The Dobson ozone spectrophotometer.—This is still the main source of ozone data. It is mostly used to measure 'total ozone' but, given suitable conditions (clear sky for several hours), it can be used to get information about the vertical distribution of ozone—using the so-called Umkehr effect. As an instrument for measuring total ozone it is capable of quite high accuracy (5 per cent or better) but depends upon a knowledge of the solar spectrum, and of the ozone absorption coefficients at the several wavelengths involved. Papers were presented which demonstrated that absorption coefficients given in the World Meteorological Organization manual for the instrument must be wrong—in some cases by 5 per cent or more (leading to errors of the same sort in deduced ozone amounts). Existing laboratory measurements of these absorption coefficients relate for the most part to 'room' temperatures; it is in the extrapolation to the low temperatures of the high atmosphere that the difficulty lies. The Commission stressed the need for laboratory determination at these low temperatures.

The Dobson spectrophotometer can be an absolute instrument since the constants of the instrument can be determined *in situ*. However, the determina-

tion of the constants can be carried out accurately only at stations in low latitudes and when skies are clear; even then a fairly intensive observational programme is required. In practice most new instruments are calibrated against a 'standard'—in Europe either No. 1 which is held by Dr. Dobson, or No. 2 which is held by the Meteorological Office, Bracknell—and subsequent instrumental drift is monitored by means of 'standard lamp' techniques. The 'standard lamp' techniques used are known to be unreliable and several papers were presented discussing, but not really resolving, the problems.

The accuracy of vertical distributions deduced from Umkehr observations was severely questioned in two papers (Bibby, United Kingdom and Mateer, U.S.A.). There was agreement that the height of the 'centre of gravity' of the ozone layer could be accurately determined and that if the ozone distribution was known up to some height, e.g. from a balloon sounding, then a mean concentration over the next 5 km or so could be assessed with reasonable accuracy. Considerable doubt was expressed, however, about whether the observations could give anything more of value. On the other hand it was remarked that charts of ozone distributions, based solely on Umkehr, seemed to be self-consistent and 'sensible' and therefore, it was suggested, of value. It was this consideration that led the Ozone Commission to accept an offer from Dr. Godson, on behalf of the Canadian meteorological service, to process Umkehr data, for inclusion in the Canadian ozone publication, using a computer technique developed by Dr. Dütsch.

(The Dütsch programme, or any similar programme, produces from a set of Umkehr results a vertical ozone distribution which, all agree, is likely to be significantly different from the true distribution. But, if the reduction technique is fixed, the distribution obtained is unique and does, of course, depend upon the actual ozone distribution. Therefore if the total ozone distribution varies systematically with time and position it is not especially surprising that the 'Dütsch' distributions also vary systematically. The 'Dütsch' vertical distributions will usually be wrong: the question is whether, bearing in mind the uses to which they are put, the results can be seriously misleading. There were no reasoned arguments on this subject, one way or the other.)

Ozone in polar regions.—Wardle (Cambridge University) described a stellar spectrophotometer (developed with the help of a grant from the Meteorological Office) primarily for use in the Arctic. Ozone measurements were made at Resolute Bay (74°N) from 13 December 1963 to 20 March 1964. The measurements indicate a more-or-less steady rise of 250 Dobson units in total ozone during this period from about 300 to about 550 units, with a scatter about this rise of ± 50 units. During February and early March large erratic variations in total ozone over periods of a few hours were recorded. For example on 2 March the amount fell from 524 units at 0720 GMT to 425 at 1015 GMT.

Aldaz (University of New Mexico), reporting on ozone observations in Antarctica, tentatively reported that he found no accumulation of total ozone during the winter and that large changes in the thermal structure of the stratosphere did not seem to be accompanied by large changes in the shape of the vertical ozone profile. (The first of these conclusions appears to differ from Wardle's findings in the Arctic.)

Ozonesondes.—Various types of ozonesonde were described—both optical and chemical. Optical sondes have the advantage that they provide

information about ozone above the sonde ceiling but reduction of results is laborious and the accuracy is low. The Regener chemiluminescent sonde has the advantage of very fast response (so fast that it was suggested it could be used in effectively free fall after ejection from a rocket at 60 km) but it seemed to be agreed that the Brewer type was rather easier to use.

A new chemical sonde, using carbon-iodine, was also described.

Rocket soundings.—Two papers described rocket techniques. In the first, ultra-violet radiation from the sun was monitored during the ascent of the rocket, using optical filters to isolate four wavelength regions each about 50 Ångströms (Å) wide. Eight flights had been made. From the first seven, for one reason or another, no results had been obtained. The last had only then just been fired. The results, we were told, 'look good' but they had not been analysed.

In the second, ultra-violet light from the night airglow was monitored in two wave bands—2400 to 2800 and 2400 to 3000 Å—again using optical filters. Only one rocket had been launched. This had been intended to make astronomical observations but, owing to a malfunction of the rocket, the astronomical experiment failed and, by an accident, it was possible to determine instead a vertical ozone distribution. Results from this experiment are given in a later section.

Chemical and photochemical processes in the atmosphere.—The chemical and photochemical processes responsible for the formation and destruction of ozone were considered in a number of papers. It was apparent that present estimates of photochemical equilibrium amounts may be seriously in error because of

- (i) a lack of knowledge of the solar spectrum (it was stated by one speaker that an accuracy of better than one part in 1000 was needed!);
- (ii) neglect of certain reactions (one speaker regarded X-ray radiation as important);
- (iii) uncertainty about certain rate constants and absorption coefficients.

Brewer (Toronto University), who has been measuring solar intensity at 2100 Å (a weak 'window' in which radiation penetrates to below 15 km), stated that his measurements showed that present figures for the solar intensity and for the oxygen absorption coefficient at this wavelength are in error by 25 per cent or even more.

Two papers were presented which suggested that ozone is destroyed by dust at high levels. A persistent dip which had been noted over Boulder, Colorado, at 50 mb over a four-week period from 9 March to 10 April 1964, was, it was suggested, caused by a layer of volcanic dust at that level.

Ozone in the troposphere.—A few papers discussed the measurements of ozone near the ground and the destruction and creation processes in the troposphere. The role of thunderstorms seemed to be regarded as small but reports of ozone in ice caves had led one experimenter to try to produce ozone by shaking ice cubes in a tumbler. He reported that he had succeeded.

Ozone above 30 km.—The only measurements of ozone at levels above balloon ceiling (apart from Umkehr) were the night airglow rocket results. The ozone concentration measured at 60–65 km was, as anticipated from theoretical considerations, some 10 times the supposed day-time equilibrium values.

The '26'-month period.—More evidence was produced indicating the presence of an approximate 2-year periodicity in total ozone. Godson (Canada) presented a preliminary report on 'an extensive program of generalized harmonic analysis of hundreds of series of solar and geophysical parameters'. He reported that he frequently found a double peak, corresponding to periods of about 22 and 26 months and pointed out that the beat frequencies of oscillations of period 1 year and 11 years have periods of 22 and 26.4 months. He stated that he found these two frequencies, for example, in an analysis of upper air temperatures over Crawley, at all levels between 200 and 60 mb.

Lindzen (Harvard University) reported on an investigation on the interaction between photochemical processes and radiative equilibrium, and of both with hydrodynamics. His thesis seemed to be that a change in ozone concentration would result in a change in the radiative equilibrium temperature and this, in turn, in a change in the ozone photochemical equilibrium. He concluded that the consequence of a perturbation could be an oscillation rather than a simple decay.

Lindzen then extended the same sort of study to a well-defined hydrodynamical problem—the vertical propagation of a wave symmetric about the equator and about the earth's axis. He concluded: "A dispersion relation is obtained which describes a wave similar, with respect to phase speed and relative amplitudes of velocities and temperatures, to the observed 26-month oscillation".

The sunspot cycle.—Willett (Meteorological Department, Massachusetts Institute of Technology) returned to the attack and produced further evidence, which struck many as convincing, for his correlation between total ozone and the sunspot cycle.

Sekihara (Meteorological Research Institute, Tokyo) reported on efforts to detect a direct solar relationship with ozone by looking for correlations between ozone and geomagnetic disturbances. He found a rather complex correlation pattern and suggested that perhaps X-rays were destroying ozone.

The general circulation.—Many papers dealt with ozone either as a tracer or as a parameter in determining the general circulation. In a report of an analysis of the first year's operation of the U.S.A. 11-station ozonesonde chain (extending from the Canal Zone in the south to Thule, in Greenland, in the north) Hering and Borden (Air Force Cambridge Research Laboratories, Massachusetts) conclude: "Composite analysis of the distribution of ozone and potential vorticity during the winter and spring months indicates that mixing in the meridional plane in the lower stratosphere occurs predominantly along surfaces which slope downwards by approximately 5 km from 30°N to 60°N. Comparison with the mean slope of the isentropic surfaces confirms the results of studies showing that the lower stratosphere is a region of northward, counter-gradient, heat flux and a region in which kinetic energy is converted into potential energy".

Several other speakers, notably Reed (University of Washington) discussed the counter-gradient flux of ozone (which can occur if there is a sloping 'preferential surface' of mixing) and stressed the importance of this in any study of the distribution of ozone.

R. FRITH

REVIEWS

The mechanics of aerosols, by N. A. Fuchs (translated from the Russian by R. E. Daisley and M. Fuchs). 10½ in × 7 in, pp. xiv + 408, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1964. Price: £6.

To those active in the field of aerosol science the work of N. A. Fuchs has been known for a long time and the publication of an English translation of his book will be a welcome event. The Russian edition appeared in 1955 and was followed in 1961 by an addendum written specially to bring the work up to date (i.e. to 1960) for translation into English.

According to Webster's Dictionary an aerosol is 'a suspension of ultra-microscopic solid or liquid particles in air or gas' and according to Green and Lane in their book on particulate clouds the term was coined near the end of the First World War to represent the aerial counterpart of a hydrosol or liquid colloidal suspension. Not surprisingly the term has come to be used in a looser sense than originally intended and in the present book the term encompasses particles of radii in the range 10^{-7} to 10^{-1} cm, well outside the range of 10^{-5} to 10^{-4} normally associated with ultramicroscopy.

As the author explains at the outset his aim is to review and critically examine all theoretical and experimental work on the motion of particles under the action of external forces, also taking into account where necessary the effect of the interaction of the particles themselves. This aim is achieved under the following broad headings: physical classification (size distribution, structure); motion of various kinds (steady rectilinear, non-uniform rectilinear, curvilinear); diffusion and deposition by Brownian motion and by forced convection and turbulence; coagulation; detachment by wind action; fluidization of powders. There are nearly 900 references to original papers and other books.

To the physicist concerned with one aspect or another of particle physics, in laboratory work and in industrial processes, there is no doubt that the book will be a valuable reference volume and an authoritative guide. For the meteorologist in particular there are two specific applications, namely in the microphysics of clouds and in the dispersion of particulate material in the atmosphere. The chapter on coagulation devotes about 10 pages to reviewing the work on the collision and coagulation of droplets as a result of their relative motion, and this chapter includes leading contributions made in the U.K. up to 1960. The chapter on convective and turbulent diffusion runs to nearly 40 pages, of which the last 15 pages are specifically devoted to the movement of aerosols in the atmosphere, and much of the remainder, in dealing with flow in pipes and ducts, is also relevant to the atmospheric problem. The classical milestones in the treatment of diffusion in this country are given proper place but, surprisingly in the circumstances, there is no reference to work which has emanated from Moscow on atmospheric diffusion, notably that of Monin, which is well known here. Otherwise the treatment is reasonably up to date and comprehensive for 1960, and it is noteworthy that important issues such as the distinction between Eulerian and Lagrangian properties, and between the spread of a cluster of particles and that of a continuous release of particles, are well recognized. To those concerned with the latest development of the science of turbulence and diffusion some differences of view will inevitably occur. For example, on a purely formal matter, the author's first reference to a Lagrangian system (p. 258) will not be acceptable to fluid dynamicists!

Again, but in a more important practical matter, the second item in the author's summary (p. 283) of requirements for further progress in problems of atmospheric diffusion shows an unawareness of what can be achieved by reasonable adaptation of the statistical theory of turbulence.

Those responsible for the translation and editing thereof are to be warmly congratulated. It is only in very occasional places that a choice of word or phrase betrays the work as a translation. There are very few misprints and omissions. The tables and diagrams are excellent and here the only improvement which this reviewer would request is the inclusion, with the table or diagram, of a reference to the source of the data. The printing and binding are also of high quality and altogether the book can be highly recommended.

F. PASQUILL

The structure of atmospheric turbulence, by J. L. Lumley and H. A. Panofsky. 9½ in × 6 in, pp. xi + 239, *illus.*, John Wiley & Sons, Glen House, Stag Place, London, S.W.1., 1964. Price: 72s.

The study of atmospheric turbulence in the lower atmosphere has developed considerably in the last decade and the classic work of the early 1950's, Sutton's *Micrometeorology*, which largely encompassed the whole subject in a single book, would now if written with the same comprehensiveness fill several volumes.

The arrival on the scene of Lumley and Panofsky's book is therefore very welcome and it takes its rightful place on the shelf beside Priestley's *Turbulent Transfer in the Lower Atmosphere* and Pasquill's *Atmospheric Diffusion*, to form a trio of books which go a long way to spanning, with an up-to-date account, the subjects of atmospheric turbulence and transfer processes.

Lumley and Panofsky purposed to summarize the basic characteristics of turbulence of meteorological interest as derived from the hydrodynamical equations and to bring up to date the observational data including recent Russian observations. They have succeeded admirably. Just under half the book deals with the statistical description of turbulence in terms of the now familiar covariances, correlations and spectra and the many subtle related problems and connexions between them. These were dealt with to some extent in Pasquill's book, of course, but on comparison one is constantly struck with the complementary nature of the two accounts. Pasquill was concerned with diffusion of smoke and particles and was therefore writing with the practical meteorologist, rather than the mathematician, in mind. It was none the worse for that. Now Lumley and Panofsky have produced this rather more academic account which the theoretician is bound to appreciate; it is thorough and detailed and should be particularly valuable in the Universities.

The second part of the book deals with the observational material, beginning with the profiles of temperature and wind close to the ground. Convection is briefly dealt with, being in a sense an addendum to Priestley's book in the light of more recent observations and the development of Monin and Obukhov's similarity theory. Then comes a chapter on the magnitude of turbulent fluctuations followed finally by an account of spectra and the scales of atmospheric turbulence. Both these chapters are full of very useful material and although some duplication is inevitable they provide a welcome expansion of the sections in Pasquill's book on these topics.

At the end of the book are two short appendices in the form of glossaries. The first expounds three meteorological terms (lapse rate, the perfect-gas law and Coriolis force) and is of doubtful value in a book of this calibre; the second discusses certain mathematical methods and terms and is of rather more significance.

The book is well written, the diagrams are well drawn and clearly reproduced and the whole production of the book is such that it is a pleasure to use and to read. A very useful list of references is not least of its potential uses to serious students and workers in this field. Very many problems remain to be solved—many of them of fundamental nature—along the way to understanding turbulence, but Lumley and Panofsky have here laid an important milestone.

F. B. SMITH

NOTES AND NEWS

551.578.41:548.5

Address by Professor S. Tolansky, F.R.S.

Pursuing his policy of inviting distinguished speakers from other realms of science, the Director-General invited Professor S. Tolansky of the Royal Holloway College, University of London, to lecture at Bracknell on 19 November 1964 (see Plate III). Professor Tolansky is a world authority on the structure of diamonds and has developed to a fine art the technique of multiple-beam interferometry for the examination of surfaces. The keen pleasure the speaker obviously derived from his subject was infectious and made this a most enjoyable address.

To examine the microtopography of a surface, Professor Tolansky uses the interference fringes set up in monochromatic light by multiple reflections between a semi-silvered (that is, partly transmitting but largely reflecting) plane glass surface and a similarly treated surface of the object to be examined, set a small distance apart and at a small angle to each other. The distance apart of the interference fringes can be controlled by the angle between the surfaces but the fringes themselves are height contours of the surface examined provided the reference glass surface is smooth. The difference in height of neighbouring contours is only half a wavelength of the light used (i.e. about 2500 Ångströms (Å) or a quarter of a micron). The fringes can be made very sharp and Professor Tolansky estimated that steps on the surface of no more than 2 Å could be detected and displayed, a distance comparable with molecular diameters. The magnification obtained in this one dimension (perpendicular to the surface) therefore is very much greater than can be obtained by any other means. In the other two dimensions, in the plane of the surface, the magnification is that of the microscope used to examine the fringes.

Slides were shown of the spiral growth of crystals and of the application of this technique for the examination of surface microstructure during hardness tests. An interesting aeronautical development was the use of multiple-beam interferometry to display and measure the damage caused to metal and perspex surfaces by high-speed impact of single raindrops. Specimens of the material to be tested were shot from an airgun at speeds of up to 800 mph at a drop of known size suspended on a fine fibre. These studies revealed that the damage caused by raindrops increased very considerably with speed of impact, the damage being proportional to the eighth power of the speed for speeds between 500 and 1000 mph.

Turning next to ice crystal growth, Professor Tolansky remarked on the extraordinary symmetry revealed by photographs of individual ice crystals. Not only was there the overall symmetry of the familiar hexagonal growth but even to the finest details was this symmetry preserved. Professor Tolansky maintained by analogy with the complex but symmetrical patterns of vibration observable on a metal plate in various modes of vibration (see Plate IV*), that the exceptional symmetry of the ice crystal could only be explained on the assumption that the crystal was vibrating during growth. On this theory, applicable only to growth of ice crystals by diffusion while falling freely, water molecules would attach themselves preferentially to the nodes of vibration, where there was no motion, rather than to the oscillating antinodes. The theory is a difficult one to test experimentally, and highly symmetrical crystals may themselves be very rare, but we are far from knowing the reasons for crystal growth habits of ice and Professor Tolansky's theory must clearly be taken into account.

R. F. JONES

551.508.57

New Meteorological Office wind-finding radar

On 13 October 1964 a demonstration of the new Meteorological Office wind-finding radar was given at the upper air station at Crawley, Sussex, to inaugurate the equipment (Plate V). The demonstration was attended by the Director-General and members of the directorate of the Meteorological Office, together with senior officers from the Ministry of Aviation and Messrs. Cossor Electronics Ltd., the manufacturers.

The new radar, the first of its kind to be accepted by the Meteorological Office, is known as the Cossor 353D and complies with a Meteorological Office specification calling for a range of operation of 200 km together with enhanced accuracy to permit the satisfactory determination of upper winds at this long range. There are no height limitations, as such, to the operation of the wind-finding system, and the range of 200 km will ensure that virtually all wind-finding balloons will remain within the field of the radar while ascending to 100,000 ft, whatever the prevailing wind speed.

The radar, which will be styled the 'Meteorological Office Wind-Finding Radar Type 4' (MOWFR 4) has a number of features, novel in British wind-finding equipment. The aerial system can be remotely controlled from an optical director for the initial location of the balloon and radar target by visual means, and there is a system for acquisition by radar when the balloon is obscured by fog or low cloud. The balloon, once so located, will subsequently be followed automatically for the remainder of the flight.

Observations of range, elevation and azimuthal bearing are provided at intervals which may be varied from 1 minute to 15 seconds, the dials indicating these values being held stationary during the period of reading.

Steps are now being taken to secure equipment which will present these values in printed tabular form, as a step towards the possible automatic computation of the wind measurement itself.

*BENTLEY, W. A. and HUMPHREYS, W. J.; Snow crystals. New York, McGraw-Hill Book Co., inc., 1931.

The radar equipment is built into the existing offices of the station thus providing considerably improved operating conditions compared with those of the previously trailer-mounted radar. In all, 11 of this type of Cossor radar are on order, for use at both home and overseas upper air stations.

A. L. MAIDENS

OBITUARY

Mr. John Wemyss Reid.—It is with deep regret that we report the death on 9 October 1964, at the early age of 29, of John Reid, Scientific Assistant. His many friends and colleagues will remember him not only for his conscientious work, but for his cheery disposition and unfailing ability to instil humour into the daily round.

John Reid joined the Meteorological Office in August 1954 and accepted a permanent appointment early in 1959. When he came to Preston from Eskmeals towards the end of 1957, he had already experienced a wide variety of work, including radiosonde duties, at a number of outstations. Apart from a short detachment to Blackpool, his home town, he remained until 1961 at the Main Meteorological Office at the Air Traffic Control Centre, Preston, from where he volunteered for overseas service. After an exhaustive medical examination he was pronounced fit for Germany and was posted to Wildenrath in June 1961. Here he was joined by his family and apart from one spell in hospital successfully completed his tour of duty.

He returned to Blackpool in June 1964 with high hopes for the future, and made plans for a new house which was still under construction at the time of his untimely decease. It is a great tribute to his indomitable courage that he fought on for many weeks after the doctors had given up all hope.

Our heartfelt sympathy goes to his widow and two young daughters.

H.T.D.H.

OFFICIAL PUBLICATION

GEOPHYSICAL MEMOIRS

No. 108—Gales in Yorkshire in February 1962, by C. J. M. Aanensen, M.Sc.

Geophysical Memoirs No. 108 deals primarily with the gale of 16 February 1962 which produced great damage in the Sheffield area in particular, and on the eastern slopes of the Pennines in general. Descriptions are given of the damage to buildings in Sheffield and to trees in north-east England. The synoptic situation which produced the gale is investigated and a survey of the pressure and wind fields on both a synoptic and meso-scale is followed by consideration of lee-wave phenomena. Calculation on a two-dimensional basis of the standing resonant lee-wave pattern gives an explanation of the gale. A calculation for 12 February 1962 also shows why a similar synoptic pattern on that occasion was not accompanied by severe gale damage. The similarity with occasions of previous westerly gales in Sheffield and possible frequency of such gales is discussed.

CORRIGENDUM

Meteorological Magazine, December 1964, p. 359, Table I; for "Height of freezing-level above the ground (gpm)" read "Height of freezing-level above the ground (mb)."

THE METEOROLOGICAL MAGAZINE

Vol. 94, No. 1113, April 1965

SIR DAVID BRUNT, K.B.E., F.R.S.

In June 1956, on the occasion of Sir David Brunt's seventieth birthday, the *Meteorological Magazine* published an appreciative account of his life and work by the Director-General of the Office, Sir Graham Sutton. It was a happy occasion and the warm tribute paid in that birthday notice should be read again at this time. Written by one who had known Sir David intimately over many years it captures the spirit of his scientific work and presents a picture of a remarkable personality in a way which no short account can improve upon. The present notice is an endorsement of that earlier tribute, made on behalf of many members of the staff of the Meteorological Office for whom Sir David's death on 5 February 1965 was a sad reminder of the debt they owe to one of the greatest personalities in their professional lives.

Although Brunt's famous textbook *Physical and Dynamical Meteorology* appeared more than thirty years ago there is probably still no meteorologist in this country, however young, who has not profited from its pages. It is something in which the Office may take satisfaction that this pioneer work was compiled while its author was a scientific civil servant and a member of the staff. Although he may be better remembered as a distinguished professor, effectively creator of the Department of Meteorology of the Imperial College, and as one of the most influential figures in the academic scientific world of his day, through his nine years as Physical Secretary of the Royal Society, yet it was the period of nearly twenty years spent in the Meteorological Office from 1916 to 1934 which provided the incentive and opportunity to survey the science of meteorology over a very wide field, to make important original contributions and to put together an outstanding textbook. It was also in his period in the Office and under his wing that full-time research into the problems of turbulence and diffusion was begun by a Meteorological Office unit at the Chemical Warfare Experimental Station at Porton. N. K. Johnson, O.G. Sutton and P. A. Sheppard are three who served in that distinguished unit during the time when Brunt was the responsible "Superintendent."

One recalls an occasion—it was the Centenary of the Royal Meteorological Society in 1950—when Brunt, in a characteristic address, claimed that meteorology was not only a science, it was a way of life. An occasion of that kind encourages and justifies extravagance but for Brunt himself it was no exaggeration: in meteorology, for many years, he found endless variety and satisfaction. It will not be as a synoptic meteorologist that he will mostly be remembered,

although his early period with the Army in France—when Lt. Col. E. Gold was his Commanding Officer—gave him first-hand experience of forecasting from which he was always ready to recall some remarkable successes when forecasting became the topic of conversation. But Brunt was never at a loss for a story drawn from his rare experience—with the military world, the Whitehall world, the academic world and later, the business world where one of his appointments was as Chairman of the Electricity Supply Research Council.

The career of Sir David Brunt was an outstanding example of a road to success which, in his time, began perhaps more frequently in Wales or Scotland than in England but was everywhere difficult to follow before the days of educational grants for all. From a remote Welsh village where the little school was in the hands of one teacher, Brunt passed through the Intermediate School at Abertillery, on to the Aberystwyth University College where he graduated with high honours in Mathematics, thence to Trinity College, Cambridge, for the Mathematical Tripos (1910), which was followed in 1913, at the age of 27, by the beginning of a career as a University lecturer. Possibly this would have led to a satisfying life as scholar and teacher had not World War I given an opening for the exercise of those wider talents for administration and negotiation which were to find their full scope in the work of the eminent Secretary of the Royal Society, an office which he relinquished in 1957.

Many will also wish to recall that Brunt was, especially during the difficult years of World War II, a tower of strength in the Royal Meteorological Society which he served in many capacities, including the Presidency from 1942 to 1945, and whose awards he was proud to have received. Brunt took pleasure from success and he was visibly warmed by recognition when it came his way, but of him, more than most, it can be said that his efforts were always to advance a cause in which he believed intensely, and few could claim to have been so consistently successful. Science generally and meteorology especially owe a great deal to David Brunt.

R. C. SUTCLIFFE

551.501.45:551.577.21:311.214:681.14

THE PROCESSING OF RAINFALL DATA BY COMPUTER

By A. BLEASDALE and A. B. FARRAR

Summary.—This article outlines some of the methods which have been developed in the Meteorological Office during the last few years for using an electronic computer in the routine work of checking and summarizing rainfall data. The types of data error are listed as well as the steps of a computer programme designed to carry out objective quality control rapidly on a very large amount of data. It is pointed out that summaries and analyses of data can be produced by computer much more quickly than by hand, and that the computer permits new methods of presentation. Some types of improvements in the various computer programmes are discussed.

Sources and nature of rainfall data available.—There are at present more than 6000 rainfall stations in the United Kingdom (Great Britain and Northern Ireland) distributed over an area of about 94,000 square miles (244,000 square kilometres). The number has increased from about 5000 since 1930. Roughly three-quarters of the stations are in England and Wales, representing rather less than two-thirds of the total area.

The distribution of stations is very uneven. Over an area of more than 1000 square miles in and around London the average density approaches 1 station

for 4 square miles (about 10 square kilometres). But in some areas, especially in northern Scotland, the density fails to reach 1 station for 100 square miles. The distribution is very broadly influenced by the distribution of population, though there are some pronounced departures from this rule, notably the relatively dense rain-gauge networks in many of the reservoird mountainous areas and some curious anomalies in the opposite sense in a few moderately well-populated areas.

Synoptic and climatological stations make up about 10 per cent of the rain-gauge network; but with regard to rainfall data alone, all stations belong to two main types. The majority contribute daily values based on measurements made once a day at 0900 GMT (the rainfall day is defined accordingly). A substantial minority, about 25 per cent, located largely in mountain and moorland areas, have monthly gauges read (nominally) at 0900 GMT on the 1st day of the month only. A small number of weekly gauges, with supplementary readings on the 1st day of each month whenever the occasion is not covered by a weekly reading, are included with the monthly gauges for the purposes of this discussion. The detailed information obtained from the charts of a few hundred recording rain-gauges has not yet been considered in the context of regular routine computer processing, though some special investigations using recording rain-gauge data have been carried out using computer techniques.

Under present consideration there are therefore, for each month, several thousand returns of daily values of rainfall, and about 1500 monthly totals in addition. At the time of writing (1964) all such data for England and Wales are processed by computer on a monthly routine, supplemented by an annual routine covering the whole body of data for the calendar year. Data for Scotland and Northern Ireland will sooner or later be included in the monthly routine, though it is thought that existing computer methods may not be adequate for areas of very sparse data, and supplementary examination of such data may remain necessary, unless networks are improved in these areas.

Types of error.—The data as received are very variable in quality, ranging from the virtually perfect to a small quantity of material which cannot usefully be amended and must be rejected outright. The overwhelming mass of data, however, contains very useful information, the value of which is substantially increased as a result of quite minor corrections. The faults which occur may be classified as follows:

- (i) Systematic errors due to faulty exposure or defective equipment.
- (ii) Occasional errors due to temporary disturbance of exposure or mischievous interference. (Occasional errors could possibly be due to temporary instrumental faults, soon detected and rectified, but this would be rather rare. A more familiar situation is the detection, after some delay, of a progressive deterioration, a case which merges with (i)).
- (iii) Misreadings, misplaced decimals, mistakes in copying, mistakes in arithmetic, and so on.
- (iv) Inadvertent omissions (observations made but not written down).
- (v) Accumulations over more than one day, sometimes indicated, but quite frequently entered as normal daily readings.
- (vi) Displacement of correct readings to incorrect days, persistently, fairly often but irregularly, or only occasionally and erratically.

(vii) Displacement of partial amounts due to deviations from standard times of observation.

Faults (i) and (ii) cover incorrect catch, and correct catch transferred to an incorrect measure; faults (iii) to (vi) cover inadequate observation and recording of measurements which may be quite correct in themselves. Faults of more than one kind may be combined. The full list applies, of course, only to daily rainfall data and not to monthly totals. Examples of the former, as received, with notes on suggested amendments, are given in Appendix I.

Objects of computer methods.—In the present context the objects of data treatment in general may be summarized under two broad aims. The first is to detect faults and to eliminate, correct or allow for them. Somewhat arbitrary criteria must be adopted for the rejection of data which are shown to be probably faulty but cannot be adequately corrected. The second general aim is to summarize and analyse the data in various ways so that important features may be brought forward, and presented in compact forms, such that the results may be readily appreciated and assimilated.

In relation to these aims the introduction of computer methods has the following main objects:

(i) To carry out quality control on a very large amount of data quickly, by methods which are strictly objective and uniform. Any variations of method which are introduced are planned, deliberate variations. Quality control by the older methods was likely to be marred by unrecorded subjective variations; these methods, if thoroughly and carefully carried out, were very tedious and slow.

(ii) To produce summaries and analyses of the data much more quickly than by hand; as a consequence to include far greater amounts of data in the simpler but possibly laborious summaries, and to carry out much more elaborate analyses for which the labour, by hand methods, would be prohibitive as a routine and could be undertaken only occasionally in special investigations.

Maps.—At the present stage of development the plotting of rainfall data on maps and the drawing of isopleths for individual occasions or for months, seasons or years, either in absolute measure (inches or millimetres) or in percentages of average, is a very important process both as a method of summarizing and presenting the data and as a form of quality control, since faulty values may often be readily detected and investigated during this process. Whilst the extension of computer methods to cover this field thoroughly cannot by any means be ruled out as a future development, as yet this has not been attempted, except that some data are tabulated by computer in a form which is very convenient for hand plotting. This may be specifically arranged or may happen as a by-product of some other computer process.

The computer programme.—The computer programme at present in use has been under development for a period of four or five years. After an experimental period it was first introduced into routine work, covering about half the data for England and Wales, in January 1962, and the routine was extended to cover the whole of the data for England and Wales in January 1963. It has not yet reached its final form and only a general description will be attempted, since anything more detailed would very soon require amendment. Changes which have been made from time to time as a result of experience are of two general types:

- (i) Changes designed to increase the precision, or otherwise improve the quality, of a computer operation and of the resultant product.
- (ii) Changes designed to simplify a computer operation, without seriously affecting the quality of the resultant product, in order to increase the speed of the operation or to relieve the load on the capacity of the computer, so that a larger amount of data can be processed in one operation. This type of change includes the elimination of unnecessary operations, the results of which have been found in practice to be covered by other operations.

Quality control.—The basic idea of the quality control part of the programme was, to begin with, to construct a reasonably close analogy with the former subjective hand and eye procedures for detecting the various types of error. From the start it was realized that this analogy could not be exact, and that whilst the new methods would prove to be in some respects better than the old, in other respects they would perhaps be poorer. A rough correspondence was aimed at in the confident expectation that the computer procedures, once started, could be steadily improved.

Whether by the old methods or the new, quality control of data is of course carried out in two main stages. The information for each separate station is checked for completeness and internal consistency and then the information for each station is compared with that for neighbouring stations, to detect anomalies lying outside acceptable limits of variation, which are estimated from what is already known to be possible in nature.

It is worth noting that although at both stages there can be difficulty in making a confident estimate of a necessary correction, the evidence that some error is present is always more definite if it occurs at the first stage than if it occurs at the second. However strong the evidence may be, it is very often true to say, at the second stage, that the suspected value could possibly be correct.

Steps of the computer programme for quality control.—The steps of the computer programme covering the two main stages are carried out month by month on the data for stations grouped in areas which are based on natural river basins. A number of the steps constitute specific tests which the data are required to satisfy and a value which does not satisfy the test is printed out against the station number with some form of coded information about the suspected defect. For any one month and a particular area, the steps may be briefly described as follows:

(i) The data are punched on tapes in a form which already includes various indicators used in the subsequent processing, one of which denotes a known error of the accumulation type (page 99), that is a value representing an accumulation over more than one day amongst regular daily values.

(ii) Allowing for (i), a count is made of the number of daily readings in the month at each station, and the sum of these readings is checked against the monthly total.

(iii) Values for the minority of stations reporting in millimetres are converted to inches and values for the minority of stations reporting 12-hour amounts are paired to make 24-hour amounts.

(iv) Any indicated accumulation in (i) is apportioned over the appropriate number of days by straightforward comparison with the mean daily values for a small number of neighbouring stations; this number is usually six but variation is allowed for in areas of low network density where there are fewer than six other daily stations within about 12 kilometres (but see page 104).

(v) For each day of the month the spatial variability of rainfall over the area is assessed by calculating the mean and standard deviation of the station values within the area, using all stations with (apparently) complete data. All daily values are then checked to pick out those which seem too high or too low. Allowance is made for stations with relatively high or low average annual rainfall (a.a.r.) compared with that for the whole area, the ratio of area a.a.r. to station a.a.r. being used as a scaling factor. Otherwise daily values for many high-altitude, high average rainfall stations would be printed out repeatedly for inspection, and similarly for some low average rainfall stations.

(vi) All zeros are now tested for any day on which the mean for the area is more than 0.10 inches (2.5 mm) and the standard deviation of all values for the area is less than the mean. Some of these will already have been printed out for inspection under (v). Such zeros are tested for inadvertent omissions, accumulations (other than those dealt with in (iv)) and displacements (page 99). The computer seeks the first non-zero value, later by date and then, if necessary, earlier by date, and tests for possible excess. Some of these excess values may already have been selected for inspection under (v). If excess is found, the value is apportioned as for indicated accumulations (iv). A value correctly measured but entered against the wrong date will usually be shown in the form of an overwhelming apportionment against the correct date. If neither accumulation error nor displacement error is found as a probable explanation, the print-out of the suspected zero suggests a missing value.

(vii) Monthly values from monthly rain-gauges are now brought in, to be checked together with the monthly totals from daily rain-gauges. Each value is tested by comparison with the mean of the six nearest stations, the departure from this mean being expressed as a proportion of the standard deviation of the six values. As with (iv) a smaller number than six is allowed for in areas of low network density. (Note: this test as originally written into the computer programme was carried out on monthly totals expressed in absolute measure (inches). It is proposed to modify the programme to include also the same test on monthly totals expressed as percentages of average annual rainfall for each station, and to compare the relative effectiveness of the two alternatives.)

(viii) A full print-out of all daily and monthly values is made, with one column for each station, the station order following a regular, familiar system so that the print-out of all suspected values from the earlier steps can be readily appraised by eye.

At this stage a long list of suspect values has been obtained. These are scrutinized and subjected to further checks by eye, then some are accepted as probably correct values though the computer has selected them as suspect following one test or another. For those not accepted, correspondence with observers follows in an endeavour to arrive at agreed corrections, sometimes a long and tedious process which raises problems of its own. However, the most

important fact is that through the operation of the computer programme a very large body of data has been passed as substantially correct and trustworthy, and for these data the time-consuming process of scrutiny by the former subjective methods is not necessary. It is no great disadvantage that the computer selects many suspect values for scrutiny which are eventually accepted. There should be time for this work, since the great body of trustworthy data need not be scrutinized by eye. It is important that the computer should not accept anything which would be obviously suspect by eye.

Production of summaries and analyses.—

(i) *Preliminary print-outs.*—Further stages in the computer programme are concerned with summaries and analyses of the data rather than quality control, and are carried out as an annual instead of a monthly routine. But it has been found convenient as a preliminary stage in the annual routine to print out in regular familiar station order certain information which provides a final step in quality control, namely:

- (a) Monthly and annual totals in absolute measure (inches).
- (b) Monthly and annual totals expressed as percentages of average annual rainfall for the station.
- (c) Departures of the percentage values (b) from the means for the nearest stations; similar to step (vii) (page 102), but all months of the year presented together so that a station with a series of suspect monthly values shows up very prominently. The departures are not printed if they fall within a certain narrow range, so that those which are printed indicate monthly values approaching or surpassing the criterion of acceptability. For a station with a missing value under (a) or (b) instead of a departure under (c) an estimated value is printed, this being based on the mean of the percentage values for the nearest six stations.
- (d) Seasonal percentages, based on sums from (b) but rounded off to integral values.

(ii) *Tabulations and summaries.*—The remainder of the programme (annual routine) consists mainly of quite straightforward tabulations and summaries of the data. These include estimates of areal values of rainfall, frequency distributions of daily values, and tabulations of maximum daily falls; some of the material is presented in a form which is as far as possible immediately ready for printing and publication. It is intended to develop this part of the programme to produce new forms of analysis of the data. In this sense, the frequency distributions of daily values have already been produced in much greater detail, and for a larger number of stations, than has ever been attempted hitherto, and certain other straightforward developments of a similar nature have been made. So far only one major development, presenting information in an entirely new form, has been introduced.

(iii) *Graphical presentation.*—This was introduced in an attempt to overcome the limitations of some earlier forms of data treatment in terms of rather arbitrary definitions of events, such as 'droughts' and 'wet spells'. Cumulative amounts of rainfall throughout the year are first expressed as percentages of the average annual rainfall for the station and then, in these percentages, as departures from the amounts which would accumulate at the uniform rate corresponding to the average. The results may be printed out graphically with

points at any specified interval, five days being in many respects convenient. An example is shown in Figure 1. The rapidly falling or rapidly rising sections of the graph represent the notably dry and wet periods, with a limiting slope, corresponding to no rain at all, for the former. The eventual aim is for all tabular and graphical print-out to be sufficiently clear and accurate for direct photographic reproduction. But this stage has not yet been reached.

The graphical form of presentation has several advantages:

- (a) All stations, whatever their average rainfall, are reduced to a common basis, for immediate comparison. This is important for wet periods and no disadvantage for dry periods because of the easily recognized limiting slope.
- (b) The severity and duration of any relatively dry or wet spells may be seen at a glance, and particularly interesting periods covering a group of stations may be readily picked out for further, more detailed, analysis and discussion.
- (c) It should be possible to develop this method to obtain a combined presentation of rainfall with other elements in the hydrological cycle, notably evaporation and run-off, according to realistic requirements. In particular there could be in this way an approach to a definition of 'drought' allowing for the seasonal variation of evaporation.

Some comments on the present computer programme.—The programme as it is being currently used (1964) for routine data processing covering all information received for England and Wales, has already been further developed in some respects, in readiness for a change-over to the new computer of much larger capacity. The general description which has been given applies reasonably well to the present programme and to the future version, as far as this can now be foreseen, but a few comments on matters of detail may be useful.

Size of area processed.—With the METEOR computer, of relatively small capacity, the data are processed area by area, covering up to 256 stations at a time. With the larger computer it will be possible to group the data within larger areas, at the same time allowing for some overlapping of areas and thereby eliminating a weakness which at present affects the procedure for some stations near the edges of certain areas. It will never be possible to eliminate this weakness entirely for stations near the coasts but this applies equally to any method of quality control.

Check with adjacent stations.—At an early stage in the development of the quality-control programme a phrase such as 'the six nearest stations' was interpreted literally in terms of horizontal distances. The computer was required to carry out for steps (iv) and (vii) on page 102, and the print-outs (c) (page 103) in particular, an appropriate number of sums-of-squares calculations on the differences in the eastings and northings of the grid references of the station primarily involved in the test and other stations nearby. The nearest stations thus found were enclosed within a circle centred on the test station. It was subsequently appreciated that in most cases, and probably all, virtually identical results would be obtained by programming the computer for a much quicker operation based simply on the linear sums, not sums of squares, of the differences, regardless of sign, in the eastings and northings of grid references. The

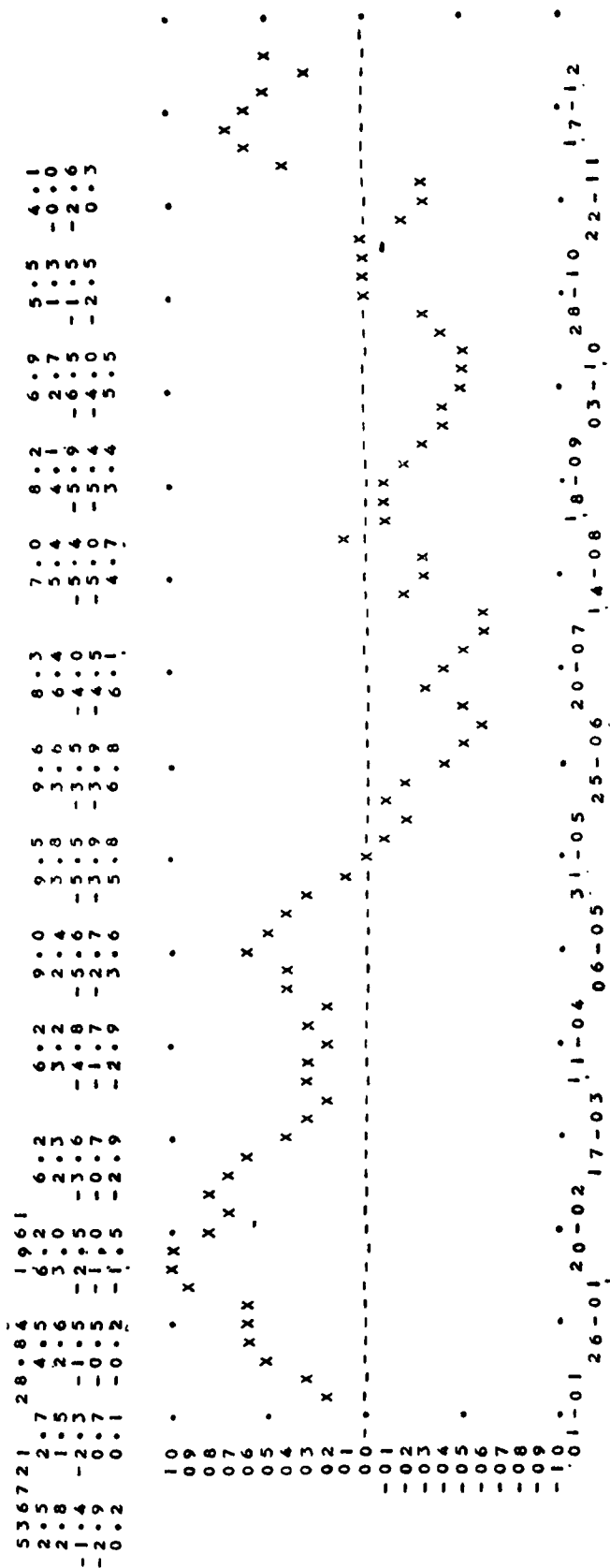


FIGURE 1—GRAPHICAL REPRESENTATION OF RAINFALL DURING THE YEAR

Top line—Station number: average annual rainfall in inches: year.

Lines 2-6—Values of cumulative departures at 5-day intervals expressed as percentages to one place of decimals.

Graph—73 points representing the values in lines 2-6 plotted by the computer to the nearest integral values.

Base-line—Dots mark 25-day intervals; below each dot are four figures, the two on the left give the day of the month and the two on the right the month on a 12-point scale from January to December. Thus 25-06 represents 25 June.

Note: The line-printer on which this figure was produced was not very accurate as shown by the rather unstable line of dashes which corresponds to zero departure. A superior machine would produce graphs of this type suitable for photographic reproduction.

nearest stations found by this method lie within a square centred on the test station with diagonals west to east and south to north. They are not necessarily the nearest stations, in terms of distances along radius vectors from the test station, but are the 'nearest' in terms of distances along rectangular co-ordinates with the test station as origin. With (e_o, n_o) as the grid co-ordinates of the test station and (e_i, n_i) for others, the test is now based on:

$$|e_i - e_o| + |n_i - n_o|$$

instead of:

$$[(e_i - e_o)^2 + (n_i - n_o)^2]^{\frac{1}{2}}.$$

The saving of computer time introduced has not been estimated, but with many, many thousands of calculations of this type every month it cannot be negligible. A further small point of interest is that for this type of operation, instead of a limiting radius of 12 kilometres which was formerly used, for the circle, a limiting semi-diagonal of 12.8 kilometres is being substituted for the roughly equivalent square. The area covered is in fact appreciably smaller but 12.8 has been selected as a very convenient number in binary form.

Treatment of multiple errors.—The outline of the computer programme which has been given, has been written, for simplicity, in such a way as to suggest that quality control is usually a matter of picking out the occasional erroneous value amongst a body of correct data. This is very often true but there is the possibility of sometimes meeting multiple errors so numerous that they could conceivably be used as the basis for adjusting correct data, or of meeting forms of multiple error with which the programme could not cope. One example of the latter might be data for a whole month, or even year, recorded incorrectly with regard to date, as with station number 255554 in example (d) of Appendix I. This is a fault immediately apparent to the trained eye and very easily corrected by the earlier subjective methods of quality control, but not necessarily so easily dealt with by the computer. In practice, in almost any rainfall régime, the computer will in such a case select as suspect such a high proportion of the rainfall amounts that the nature of the fault is readily apparent. In this and other cases of multiple error, where the data are at first sight apparently complete and self-consistent, there remains however the disturbing possibility that incorrect values may have been used to check other data. It would be possible to go through an indefinite process of recycling the data, refining the corrections introduced at every stage until all possibility of the undesirable use of incorrect data had been eliminated. In practice a single recycling, paying particular attention to wrong-date corrections, and the apportionment of accumulations, indicated or otherwise, will probably be enough. Other types of error occur very largely in relative isolation, except for the data for a very few stations which are so poor as to be virtually useless and fit only for complete rejection at the earliest stage. As yet, however, there is insufficient experience to make final decisions about the extent of the need for recycling and, so far, no attempt has been made to make the process of scrutiny and correction between cycles in any way automatic. A recycling problem also exists in the very early stages of computer processing when the punched tapes are being checked for accuracy, corrected (re-punched, at least in part), and checked again. A firm decision has not yet been made concerning the degree to which a close approach to complete accuracy should be attempted. It is obvious that all gross errors must

be eliminated but a very small number of trivial errors in an enormous mass of data would have negligible effect on any practical use of the information, and it is equally obvious that at some point striving after complete accuracy for academic reasons must become quite uneconomic.

Improvements in individual tests.—Various refinements of individual tests are under consideration. In particular when the time comes for data covering larger areas to be processed together in a computer of larger capacity, it may no longer be desirable to carry out certain steps such as (v) and (vi) (page 102) over the whole area simultaneously. Smaller overlapping areas may be used, or some different system may be developed. The testing of zeros (vi) (page 102), in particular, may need refinement, since it is certain that some accumulations at present escape detection on occasions when there are periods of a few days with low total rainfall over an area and the criterion for starting the test is not fulfilled. An important question is whether this matters very much, except for academic reasons, as discussed in a different context on page 106, provided that all the large accumulations are detected and dealt with. There is one type of test, however, which certainly requires improvement in order to make quality control by computer more independent of supplementary scrutiny by eye. At step (vii) (page 102) a station value is compared with values in the immediate neighbourhood by taking the mean and the standard deviation of surrounding values and expressing the station departure from this mean as a proportion of the standard deviation. Whenever the station value represents a near approach to a local maximum or minimum, there is a danger that the surrounding values will be very nearly equal, at a slightly lower or higher level, resulting in a very small standard deviation and a very high ratio for the station departure. The station value, on this evidence alone, is selected as suspect by the computer. To take the ratio in conjunction with the absolute value of the departure does not completely overcome the difficulty in all cases. The simplest way of overcoming the difficulty is in fact to glance at the corresponding map of rainfall distribution, if this has already been plotted, when it is usually obvious whether the station value can be accepted as a local maximum or minimum. An equivalent computer test may yet be devised but this stage has not been reached.

Systematic errors in rainfall data.—Virtually all important errors of types (ii) to (vii) (page 99) can be detected during month-by-month quality control, whether by subjective methods or by computer, given sufficient refinement of the tests. The same is not necessarily true of systematic errors which usually depend for their detection on the availability of data covering a long period of months, or preferably years, and an adequate knowledge of the variation, with altitude and other factors, of average rainfall in the neighbourhood of the station. Some of the quality-control tests themselves depend on an adequate knowledge of the spatial distribution of average rainfall. In order to minimize the influence of undetected systematic errors in quality-control tests, whilst making full use of existing trustworthy knowledge of average rainfall, a procedure has been adopted of allocating to every single station a value of average rainfall according to a threefold classification:

Class A. Stations with virtually complete trustworthy data throughout the standard period to which the annual averages refer—averages very reliable.

Class B. Stations without such complete data throughout the standard period, but with sufficient data for a standard-period average to be estimated with fair confidence.

Class C. Stations for which the standard-period average is no better than a very provisional estimate, subject to review and probably revision.

For station in classes A and B the emergence of systematic errors would be a new departure which would be readily detected and investigated at an early stage. For stations in class C it would necessarily require a fairly long process of review and reassessment before any decision could be made on the possible presence of systematic errors, or alternatively the transfer of such a station to class B. A special watch should be kept on results for class C stations during quality-control procedures.

Appendix I

EXAMPLES OF DAILY RAINFALL DATA AS RECEIVED, WITH SUGGESTED AMENDMENTS

Example (a) Probably a mistake in copying (error type* (iii)).

Station	327022	327138	<u>327153</u>	328159	328572	Suggested amendment 327153
Date						
Feb. 22	—	—	—	—	—	
23	0.18	0.10	0.18	0.17	0.17	
24	0.58	0.68	0.58	0.36	0.30	
25	0.24	0.25	0.30	0.24	0.36	
26	0.31	0.35	0.31	0.26	0.31	
27	0.62	0.54	0.59	0.57	0.57	
28	—	—	0.61	tr	0.01	0.01
Mar. 1	—	—	—	—	—	

*Error types are listed on page 99.

Example (b) Observations not very accurately made (type (iii)), recorded against incorrect dates (type (vi)) with accumulations (type (v)), one indicated, one not.

Station	311001	312780	<u>313158</u>	313317	313324	Possible amendment 313158
Date						
July 10	—	—	—	—	—	—
11	0.19	0.16	—	0.03	0.03	0.25
12	0.14	0.29	—	0.20	0.16	0.45
13	0.02	0.12	0.70	0.14	0.15	0.10
14	0.65	0.44	0.10	0.35	0.28	0.40
15	0.35	0.32	0.40	0.32	0.33	0.35
16	0.15	0.06	—	0.20	0.18	0.15
17	—	—	0.50	—	—	—
8-day total	1.50	1.39	1.70	1.24	1.13	1.70

It is doubtful if the amendment to 313158 is worth making. Throughout the whole year every daily entry except two had either 0 or 5 in the second decimal place, and most readings, including several accumulations, seemed to be very crude approximations. The possible amendment shown is very rough and based on the suggestions that the set of readings for 10–17 July should first be thrown back one day, with 0.70 now on the 12th, as an accumulation, not indicated, and 0.50 now on the 16th as an indicated two-day accumulation.

Example (c) Indicated accumulation (type (v)), no other fault.

Station	586983	590690	<u>592488</u>	592764	592849	593510	Suggested apportionment 592488
Date							
Apr. 12	0.31	0.56	0.53	0.34	0.24	0.33	
13	0.45	0.34	0.40	0.59	0.57	0.26	
14	1.72	3.35	2.78	1.24	1.18	1.36	
15	0.13	0.12	0.05	0.08	0.05	0.02	
16	0.20	0.35	0.83	0.14	0.12	0.11	0.17
17	0.81	0.63		0.74	0.68	0.52	0.62
18	0.11	—		0.06	0.03	tr	0.04
19	—	—	—	—	—	—	

Example (d) One observation recorded against incorrect date (type (vi)).

Station	253174	253749	254432	<u>254651</u>	254820	255554	Suggested amendment 254651
Date							
May 25	—	—	0.02	—	0.01	tr	
26	0.02	tr	0.01	0.02	0.02	0.01	
27	0.40	0.29	0.75	—	0.41	0.30	0.72
28	—	—	—	0.72	—	tr	—
29	0.16	0.12	0.16	0.18	0.19	0.08	
30	—	—	—	—	tr	—	

Station 254820. Amounts have been moved forward by one day, for this group of readings.

Station 255554. Amounts have been thrown back by one day, for the whole year.

Example (e) A small group of observations recorded against incorrect dates (type (vi)), one reading queried as very probably excessive (type (ii) or (iii)).

Station	337038	<u>337291</u>	338132	338940	339296	340174	Suggested amendment 337291
Date							
June 10	—	—	—	—	—	—	
11	—	—	—	—	—	—	
12	—	1.15	0.40	0.37	0.08	0.22	1.15 too big?
13	1.20	1.27	0.83	0.96	1.53	1.28	
14	—	—	—	—	—	0.02	
15	—	0.02	0.02	0.01	0.01	0.01	readings 15th-18th to be moved forward one day
16	0.07	0.24	0.01	0.02	—	—	
17	0.34	0.25	0.27	0.24	0.24	0.21	
18	0.26	0.18	0.14	0.04	0.07	0.10	
19	0.36	—	0.12	0.18	0.17	0.26	
20	0.03	—	—	—	—	—	
21	—	—	—	—	tr	—	

551.501.45:551.577.21:311.214

ERRORS IN THE TRADITIONAL METHOD OF COMPUTING GENERAL VALUES OF MONTHLY AND ANNUAL RAINFALL OVER LARGE AREAS

By R. P. WALDO LEWIS, M.A., M.Sc. and B. GOLDING

From 1923 until recently it has been the practice in the rainfall section of the Meteorological Office to compute monthly general (or areal mean) values of rainfall over areas such as England, Wales, England and Wales, and Scotland, by the following method:

A network of stations with reliable monthly averages for the standard period in use (1881-1915, or 1916-1950) is chosen, so that the stations are distributed

over the area in question as evenly as possible. The rainfall at each station for the month under consideration is expressed as a percentage of its monthly average, and a mean percentage over the area is found by meaning the individual percentages over all stations in the area. This mean percentage is then applied to a previously computed average general value of rainfall over the area (also referred to the standard period) in order to give the desired general areal value for the month in inches. The reason for adopting this method is that variations of monthly percentages from point to point are much smaller than the variations of the actual rainfall. The method is not exact, however, and an expression for the error introduced may be derived as follows.

Let the rainfall for a particular month at a point (x, y) within the area be r , a function of x, y .

Let the average over the standard period for that month at (x, y) be ρ , also a function of x, y .

Let $\phi \equiv r/\rho$, so that 100ϕ is the monthly percentage at (x, y) .

Let R be the true general value of the rainfall over the area, and R' the value yielded by the 'percentage method.'

Then $R = A^{-1} \iint r dx dy = A^{-1} \iint \rho \phi dx dy$ (1)
 where the double integral is taken over the whole area, and A is the magnitude of the area. Also $R' = A^{-1} \iint \phi dx dy A^{-1} \iint \rho dx dy = \bar{\phi} \bar{\rho}$
 where $\bar{\phi} \equiv A^{-1} \iint \phi dx dy$ and $\bar{\rho} \equiv A^{-1} \iint \rho dx dy$.

Then $R = A^{-1} \iint (\rho - \bar{\rho} + \bar{\rho}) (\phi - \bar{\phi} + \bar{\phi}) dx dy$
 $= A^{-1} \iint \{ \bar{\rho} \bar{\phi} + \bar{\phi} (\rho - \bar{\rho}) + \bar{\rho} (\phi - \bar{\phi}) + (\rho - \bar{\rho}) (\phi - \bar{\phi}) \} dx dy$
 $= R' + A^{-1} \iint (\rho - \bar{\rho}) (\phi - \bar{\phi}) dx dy$ (2)
 since $\iint \bar{\rho} \bar{\phi} dx dy = \bar{\rho} \bar{\phi} \iint dx dy = A \bar{\rho} \bar{\phi}$
 and $\iint (\rho - \bar{\rho}) dx dy = 0 = \iint (\phi - \bar{\phi}) dx dy$.

Thus the error of the percentage method is equal to

$$R' - R = -A^{-1} \iint (\rho - \bar{\rho}) (\phi - \bar{\phi}) dx dy. \quad (3)$$

This expression is a sort of 'areal covariance' between percentage values and average values, taken over the area under consideration and will thus not be systematically different from zero. In individual months however, its value may differ appreciably from zero, particularly when the overall patterns of average and percentage—considered regardless of sign—bear a marked resemblance to one another. An example would be furnished by the association of small percentages in the Lake District and Pennines with large percentages in south-east England since these two areas have high and low average rainfall respectively.

To determine the error in an estimate of a value it is of course necessary to determine the true value. The best way to determine the true value of R for say England and Wales is to plot isohyetal maps of England and Wales for each month and obtain R by planimetering, an immensely laborious task unsuitable for mechanization. However, it is possible to split up a large area into a large number of smaller areas, each of which is so small that the variation of percentage over it is trivial and the error $R' - R$ is thus also trivial. The percentage method is then applied to each of the small areas, and the total rainfall over the large area is found as the sum of the total rainfalls over all the small areas:

this will yield an estimate of R that is not perhaps the best possible, but one that can be expected to be much nearer the truth than the original R' .

The existence of estimates of average monthly rainfall over each county of England and Wales* made it possible to carry out calculations using the county as the basic small area. For each county (or in some cases for a small group of counties), several rainfall stations having averages for the standard period 1881–1915 were chosen so that the percentage value of the rainfall over the county could be estimated as the mean of the percentage values at the individual stations. (Lack of suitable stations in some localities was overcome by grouping certain counties together). The areas into which England and Wales were divided together with the positions of the rainfall stations used, are shown on the map (Figure 1). Certain stations were used to provide estimates of percentage for more than one county.

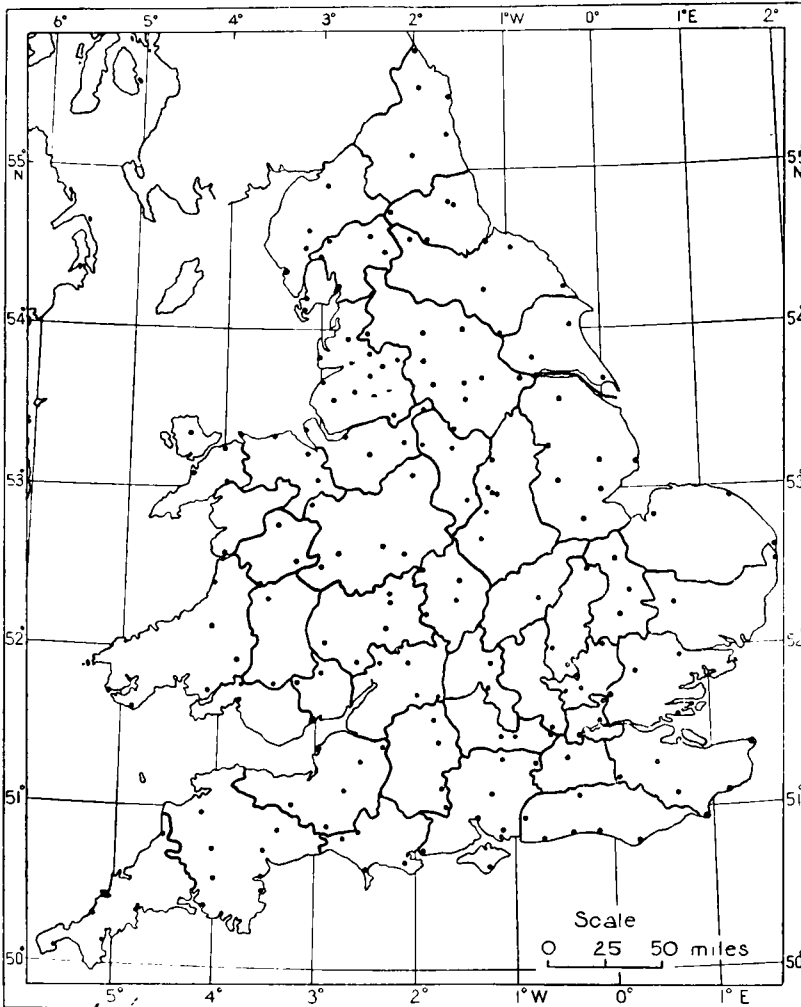


FIGURE 1—AREAS USED IN CALCULATION OF GENERAL (OR AREAL MEAN) RAINFALL WITH POSITIONS OF RAINFALL STATIONS USED

*London, Meteorological Office. Average monthly and annual rainfall over each county of England and Wales. *Brit. Rainf.*, 1950, London, 1952, p. 215.

For each month, county by county, the estimates of monthly percentage were multiplied by the appropriate monthly average of rainfall, and the resulting county rainfall totals were combined into monthly totals for Wales, England, and England and Wales. These calculations were performed on the Meteorological Office electronic computer METEOR.

There are two sources of discrepancy between the monthly rainfall figures produced by this new method and those previously published in *British Rainfall*. Firstly, there is the discrepancy due to the method of calculation, which is what we wish to determine. Secondly, there is a discrepancy because the integrated individual county monthly averages are not exactly the same as the general monthly and annual averages of rainfall over large areas used in Section 8 of *British Rainfall*.

This latter discrepancy is shown up by Table I in which the columns labelled A are the areal rainfall averages used in Section 8 of *British Rainfall*, and those labelled B are the areal rainfall averages calculated from the individual county averages. In order therefore to ensure that the areal averages used in the two methods are comparable and thus to allow a fair comparison between the estimates produced by the new method and those previously published, the former were multiplied by an appropriate factor, different for each month and large area, deduced from the figures in the table; for example, the computer estimates for Wales for March were multiplied by 3.82/4.08.

TABLE I—TWO SETS OF AREAL AVERAGES OF MONTHLY AND ANNUAL RAINFALL

Month	England		Wales		England and Wales	
	A	B	A	B	A	B
				<i>inches</i>		
January	2.69	2.59	4.72	4.84	2.99	2.90
February	2.34	2.25	3.94	3.99	2.57	2.49
March	2.47	2.39	3.82	4.08	2.67	2.62
April	1.98	1.95	2.96	3.02	2.12	2.10
May	2.19	2.17	2.95	3.04	2.30	2.29
June	2.33	2.32	3.05	3.13	2.44	2.43
July	2.75	2.69	3.60	3.70	2.87	2.83
August	3.11	3.03	4.71	4.86	3.35	3.28
September	2.37	2.30	3.51	3.59	2.54	2.48
October	3.69	3.55	5.63	5.71	3.97	3.85
November	3.19	3.06	5.25	5.35	3.49	3.38
December	3.56	3.42	6.00	6.16	3.92	3.79
Year	32.67	31.72	50.14	51.47	35.23	34.44

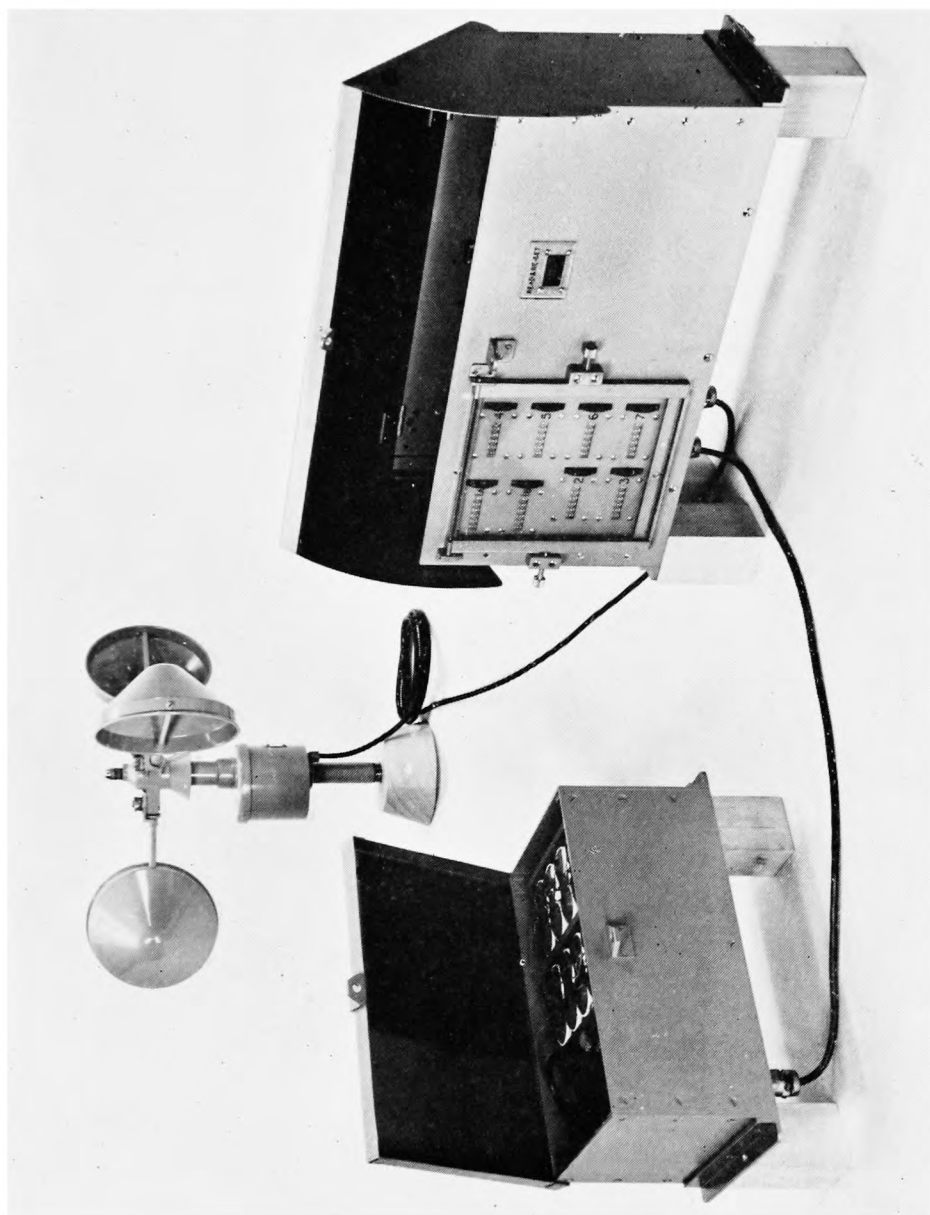
A = areal rainfall averages used in Section 8 of *British Rainfall*,

B = areal rainfall averages calculated from the individual county averages.

If the monthly estimates produced by the new method just described are subtracted from the old previously published estimates, the resulting differences may reasonably be regarded as good approximations to the errors in the old estimates.

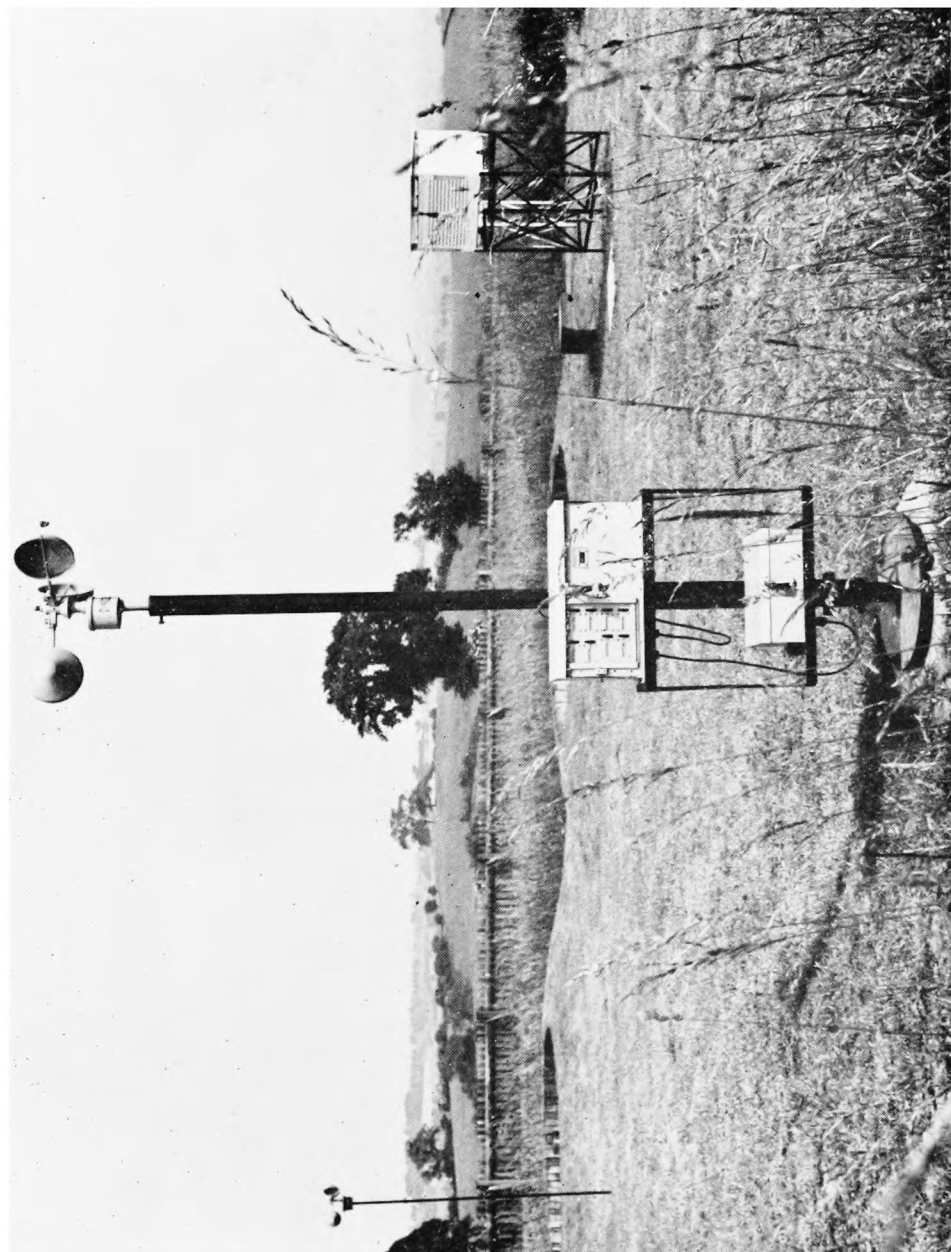
Table II shows the frequency distribution of these errors during all months of the decade 1941–50 for England and Wales as a whole and for Wales. It is clear that over England and Wales the errors were usually very small. Scrutiny of the detailed monthly figures (not given here) showed that sizable percentage errors were due to errors of ± 0.1 inch in months of low rainfall, e.g. 0.1 inch in 0.7 inch amounting to 14 per cent.

Over England by itself errors were also small but for the much smaller area of Wales the errors are seen to be larger. In one dry month the new method gave



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PLATE 1—RECORDING ANEMOMETER DESIGNED BY THE HYDRAULICS RESEARCH
STATION, WALLINGFORD

The equipment consists of battery box (left), anemometer, and recorder (right) (see page 114).
The anemometer cups are mounted 2 metres above ground.



Crown copyright

PLATE II—RECORDING ANEMOMETER DESIGNED BY THE HYDRAULICS RESEARCH
STATION, WALLINGFORD, INSTALLED ON A CATCHMENT SITE

See page 114.



Photograph by R. K. Pilsbury

PLATE III—A STRIKING DISPLAY OF MAMMA BENEATH CUMULONIMBUS TO THE SOUTH OF BRACKNELL AT ABOUT 1400 GMT ON 23 OCTOBER 1964

Showers were visible at the time to the south and west with cumulonimbus in all quadrants of the sky.



Crown copyright

PLATE IV—WEATHER PRESENTATION BY MR. NORMAN ELLIS ON BBC TELEVISION

TABLE II—DISTRIBUTION OF DIFFERENCES BETWEEN OLD AND NEW ESTIMATES OF MONTHLY GENERAL RAINFALL 1941-50

Old estimate minus new estimate <i>inches</i>	England and Wales <i>number of occasions</i>	Wales	Old estimate minus new estimate <i>inches</i>	England and Wales <i>number of occasions</i>	Wales
-0.6		1	+0.2	8	13
-0.5		2	+0.3		7
-0.4		7	+0.4		5
-0.3		1	+0.5		0
-0.2	11	10	+0.6		0
-0.1	32	24	+0.7		0
0.0	53	23	+0.8		2
+0.1	16	25	Total	120	120

0.7 inch whereas the old estimate was 0.4 inch, an error of over 40 per cent. The main reason for the contrast between Wales and England is as follows: over a medium-sized area such as Wales there can easily be appreciable variations of percentage leading to appreciable values of the 'areal covariance'; this is especially true when, as in Wales, the area includes big variations in average rainfall. Over a much bigger area, such as England, local contributions to the areal covariance may be just as large but they will on the whole tend to cancel each other out. It follows that the old method will tend to give larger errors for medium-sized than for either very small or very big areas. A secondary reason for the contrast is that the number of stations used for determining the mean percentage over Wales in the old method was rather small.

Errors in the estimates of annual totals over England and Wales ranged fairly evenly from -0.6 inch to +0.5 inch, that is, up to approximately 2 per cent; over Wales however errors in annual totals ranged from -1.3 inch to +2.0 inch, that is, up to about 4 per cent. Even over Wales, however, 8 out of the 10 years had errors of 0.6 inch or less.

The conclusion to be drawn from the work described above seems to be that the great majority of the previously published monthly and annual general values of rainfall over England, Wales, and England and Wales are as accurate as can reasonably be hoped for, but that the old-established method of computing them gives rise to substantial errors often enough to make a change of method desirable in all future work. (Such a change of method has in fact now been introduced into the rainfall section largely as a result of this investigation.)

We wish to express our thanks to Mr. P. B. Sarson who wrote the computer programme.

551.508.54

A WEEKLY RECORDING ANEMOMETER

By M. T. H. KEY

Hydraulics Research Station, Wallingford, Berkshire

Introduction.—The Hydrological Research Unit (HRU), Wallingford, is conducting water-balance investigations on experimental catchments in certain parts of England and Wales. Climatological stations have to be operated at isolated sites which can be visited only once a week.

An anemometer of the cup counter type was required to record the daily total run of the wind for a seven-day period without attention, to be independent of outside electrical supply and to be able to withstand the adverse climatic conditions of exposed positions.

A standard instrument to fulfil the seven-day recording requirement was not available, but a suitable recording anemometer (Plate I) has been designed and manufactured at the Hydraulics Research Station (HRS). The instrument has been in use on one of the catchment sites since March 1964 having previously been tested on the HRU climatological site at Wallingford since October 1963. A photograph of the complete installation on a catchment site is shown in Plate II. A comprehensive note¹ has been prepared to guide observers on the installation and on the weekly readings.

Principles of operation and general description.—The instrument was designed for use with a commercial contact anemometer providing an electrical closed circuit for each tenth of a mile run of the wind. Each daily total is recorded on one of eight counters; a clock and cam-operated micro-switch system connects the anemometer to the counters at 24-hour intervals. Every week, when the installation is visited, seven counters are read and reset to zero, the one actually operative at the time being ignored until the next visit.

The counters are battery operated. Battery life is expected to be at least 200,000 counts or 20,000 miles run of wind. A battery tester has been made for use by the observer when he visits the installation.

The three units of the equipment, comprising anemometer, recorder and battery box, are mounted on a 1 $\frac{3}{4}$ -inch diameter scaffold pole, the anemometer cups being 2 metres above the ground. The mounting frame for the recorder and battery box is arranged to swivel on the mast so that it can be rotated to the leeward side, and then, when the recorder box is opened for winding the clock or adjustment of the time dial, the cowled lid will shield the mechanism from driving rain. The counters are protected by a movable perspex flap which closes on a rubber sealing strip and which also serves as a rain shield when it is raised for resetting the counters.

The instrument may also be used to obtain mean wind speed in the manner prescribed for the cup counter anemometer Mk II.²

Acknowledgments.—The work described in this paper was carried out as part of the research programme of the Hydraulics Research Board and this note is published by permission of the Director of Hydraulics Research.

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551.501.8:061.3

1964 WORLD CONFERENCE ON RADIO METEOROLOGY, INCORPORATING THE 11TH WEATHER RADAR CONFERENCE, BOULDER, COLORADO

This conference, held from 14 to 18 September 1964, was sponsored by the Inter-Union Committee on Radio Meteorology of the International Scientific Radio Union (URSI) and the International Union of Geodesy and Geophysics (UGGI), the American Meteorological Society, the U.S. Weather Bureau, and the Central Radio Propagation Laboratory of the U.S. National Bureau of Standards in whose laboratories at Boulder it met. It was remarkable not only

for the length of its title and list of sponsors but also for its organization and procedure. The organizing committee invited papers on a number of chosen subjects; contributors were required to forward their manuscript in a specified format about four months before the date of the conference. These papers were printed by a photographic process in a paper-backed volume of some 500 pages, and the volume was in the hands of all those who had registered to attend the conference about a month before it convened. At the conference papers were not presented by the authors in the usual way. Each session was in the hands of a Chairman and a 'lead speaker.' The latter introduced the subject of the session, and was supposed to refer to all the papers and indicate their content and interrelation. The Chairman then called for discussion of the papers in turn. One or two lead speakers dwelt unnecessarily on their own work, and one or two authors evaded the Chairman's eye and slipped in a hurried presentation under the guise of comment, but on the whole the method was successful, with informed discussion of the content of the more interesting papers and of the general state of the subject. The success of this procedure implies a high degree of discipline from contributors, an unusually hard-working group of organizers, and a sponsoring Institute with considerable resources in facilities and finance. The conference volume will be a valuable addition to any library during the year or two which will elapse before the high proportion of its content which is worth preserving finds its way, in more polished and final form, into the journals and textbooks.

Four sessions were devoted to the meteorology of radio-propagation—'Radio climatology,' 'Meteorological effects on propagation,' 'Radio-refractive index measurements' and 'Tropospheric propagation, super-refraction, and scatter propagation.' The subjects were rather arbitrarily differentiated and the papers put forward no really new ideas, but in some cases brought a new degree of precision to the subject. Perhaps the most interesting new observations were those on fine-scale variation of refractive index, made mainly at Cardington and communicated by J. A. Lane of the Radio Research Station.¹

The session on 'Anomalous echoes and angels' led to very lively discussion but, not surprisingly, to no general agreement. Few were able to accept wholeheartedly D. Atlas's picture of the leading edge of an ascending thermal acting in much the same way as a well-figured spherical metallic reflector, but equally few were convinced by less precisely specified alternative explanations involving birds and insects.

The papers on rainfall measurement by radar were concerned not with the usefulness of the technique—that was not questioned—but with ways of assessing and improving its accuracy. A paper on precipitation measurement by Weather Bureau radars, for example, concluded that present methods led to an average underestimate of about 20 per cent on an area basis, with errors up to a factor of two either way in individual cases. There were many papers on drop-size distribution, which of course determines the relation between rainfall rate and echo intensity. Measurements with the Malvern Doppler radar, presented by P. G. F. Caton, made a weighty contribution to this problem.

A session on 'Scattering and attenuation—tropospheric and terrain noise radiation' contained rather a mixture of papers, as one or two on precipitation attenuation at 3 cm were caught up with the majority which were either on generalized scattering problems or on atmospheric transmission in the 1-mm to 3-cm region. On the whole the papers were educative rather than original,

introducing to radio scientists concepts which have long been familiar to students of atmospheric radiation. D. Diermendjian extended his Mie-theory work to the 1-mm to 10-cm range, and B. M. Hermann reported on a 'simple' problem in multiple scattering. Microwave spectra and atmospheric transmission functions were mentioned. Possibilities of temperature-structure measurements from satellites using microwave spectroscopy were discussed by self-styled optimists and pessimists. The great advantages of microwave over infra-red spectroscopy are the extraordinarily high resolution attainable and the sensitivity of available detectors, so long as the wavelength is not too short for true radio techniques.

The last session, on lasers, opened with an extraordinary lead speech by Professor Franken of Michigan State University, which was at once a comic turn of great distinction, a summary of the properties of available lasers in the context of atmospheric sounding and an estimate of likely technical developments. The actual work reported to the meeting was disappointing in amount and content, the most substantial part having already been published.^{2,3} Professor Franken is himself involved in the search for clear-air turbulence (CAT) by the use of laser methods, a search which has had some Press publicity. It transpired that the basis of the work was a belief that CAT might be connected with the mixing of two air masses of different aerosol content, the difference being detectable by optical back-scatter. Professor Franken himself discounted the possibility of more sophisticated Doppler laser techniques.

There was, of course, some social activity, the most memorable being an afternoon spent walking in a sprinkling of new snow in the high Rockies. Boulder itself is likely to become a centre for meteorologists, as the new home of the National Center for Atmospheric Research is now being built there, to an imaginative design, on a site of quite exceptional natural beauty. While it is hoped that the increasing urban sprawl of the town of Boulder itself can be contained, the great scientific opportunities opening up in such remarkable surroundings for the young student of our science are considered with envy.

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G. D. ROBINSON

551.510.42

METEOROLOGICAL OFFICE DISCUSSION

Atmospheric pollution

The Monday discussion held on 26 October 1964, opened by Dr. A. G. Forsdyke, covered those aspects of air pollution which are dealt with in the Special Investigations Branch (Met.O.9). These arise from particular inquiries which the branch is called upon to answer, and they draw upon the results of fundamental research, though the research itself is done in other branches of the Office and elsewhere.

Atmospheric pollution by smoke has been a nuisance in large towns for a very long time, the earliest record dating from 1273 when there were appeals to the governing authorities to ban the burning of coal at such industrial premises as then existed in London. But the first effective legislative action was not

taken until 1863 when there was set up the Alkali Inspectorate, a body which still exercises control over noxious emissions from industrial plant. Government sponsored research began in 1917, and today is carried on chiefly at the Warren Spring Laboratory at Stevenage. An important part of the work of the Laboratory is the organization of a country-wide network of stations which regularly measure and report atmospheric pollution. The serious consequences of heavy pollution were brought home by the disastrous London smog of December 1952, which led to the setting up of the Beaver Committee and the subsequent passing of the Clean Air Act, 1956. This Act empowered local authorities to designate 'Smokeless Zones' and encouraged the use of smokeless fuels and more efficient burning appliances. The result has been a gratifying decrease in smokiness over the past eight years, particularly in London. The main troublesome pollutant is now sulphur dioxide (SO_2). Neither this gas nor the sulphur from which it is derived can be economically removed from the raw fuel or the chimney effluents. Reduction of the concentration of SO_2 to below harmful levels is therefore dependent upon dispersal and dilution of the effluent in the atmosphere. In big industrial plant and power stations this is achieved by building high stacks and discharging the effluent at high speed and high temperature.

Following these introductory remarks the speaker outlined the theoretical background relating to atmospheric diffusion and turbulence. This is the basis for calculation of concentration of a pollutant in the atmosphere at any point affected by a particular source such as a power station chimney. The working formula is that proposed by Pasquill.*

There followed a description in some detail of the application of the formula in a particular inquiry dealt with in Met.O.9. This involved the calculation of SO_2 concentration at various floor levels of proposed tower-block flats between $\frac{1}{2}$ and $1\frac{1}{2}$ miles from an electrical power station with tall stacks emitting up to 10 tons of SO_2 per hour. The calculated concentration at the upper floors was above the limit of tolerance and, partly for this reason, the scheme was not proceeded with.

As a further example of a practical problem in air pollution a method was outlined for the forecasting of high SO_2 pollution levels in the City of London. Daily values of SO_2 concentration measured at St. Bartholomew's Hospital were tabulated for the five winters 1958/59 to 1962/63. These were related to the minimum night temperature at London (Heathrow) Airport (T_n °C) and the largest temperature 'inversion' (ΔT °C) calculated as the difference between the highest temperature below 900 mb on the Crawley midnight tephigram, and T_n . It was found that provided the cloud amount at London (Heathrow) Airport remained small and the wind light throughout the period, smog (defined as SO_2 concentration ≥ 1000 microgrammes per cubic metre) was likely if

$$2 \Delta T - T_n \geq 12.$$

In the subsequent discussion Mr. E. N. Lawrence described the routine methods of measuring SO_2 pollution. Dr. F. Pasquill commented on the physical foundation and the conditions of applicability of his formula on which, at present, the calculation of pollution is based in practice.

*PASQUILL, F.; The estimation of the dispersion of windborne material. *Met. Mag.*, London, 90, 1961, p. 33.

A COLLOQUIUM ON TELEVISION WEATHER FORECASTING

Mr. Robert T. Freeman, Chief Meteorologist WKY Radio and Television, Oklahoma City, was the chief speaker at a colloquium on television weather forecasting held at the Imperial College of Science and Technology, London, on 17 November 1964.

Mr. Freeman commenced by pointing out that the weather in Oklahoma is rather more settled than in this country and the winters are not very severe. Forecasts are normally only required for short periods, and in the summer months they usually consist of forecasting severe storms such as thunderstorms, hail and tornadoes. These storms can be very destructive even though they may have a relatively short lifetime. An individual storm may last only about half an hour, though a number of them forming an area of storms can continue for up to 10 to 12 hours. Rapid notification of the development of storms to the public is essential so that the optimum use can be made of the information. As the forecasting of such storms can be literally a matter of life and death it would seem that the qualifications of the forecasters must be of the highest order. However, in the United States many stations employ weather men who are not professional meteorologists. Television weather men are becoming the public image of the profession, and the aim should be for them to possess the highest possible qualifications. As a result, a system of seals of approval has been instituted by the American Meteorological Society.* Some television stations take weather forecasting very seriously indeed and have helped to educate people to the problems involved, but not all stations employ forecasters possessing the seal of approval. The only station in Oklahoma State to do so is WKY Oklahoma City.

Mr. Freeman showed a film depicting the weather set-up at WKY Radio and Television Station Oklahoma City. The weather office is close to the television studio and a full set of meteorological instruments is maintained. The readings of the instruments are displayed in the weather office and this display is duplicated in the television studio so that it can be televised. A weather radar set is also provided, with two scanners, one of which is on a high tower 11 miles away. The radar has ranges of 250, 160, 80 and 25 nautical miles. The radar set is in the weather office and the display is also duplicated in the studio, so, here again, the cameras can be trained on the radar picture whilst the presentation is taking place. There is also a switch in the studio by means of which the weather man can change the range of the radar whilst he is actually doing the presentation. By means of an 'overlay' of the State, it is possible to show viewers the areas in which storms are occurring, and this display can also be photographed to be shown at a later time. The company provides a news car which can be used by the weather section to search for and track storms or tornadoes. The film includes dramatic pictures of an approaching tornado seen against the skyline of Oklahoma City and pictures of the news car dashing off to investigate. Reports also come in by telephone from the public, and all these reports are plotted, future movements of the storms are estimated, and the information is relayed to the public. This is done by means of special bulletins, and the company gives the meteorologist authority to interrupt programmes at any time if it is necessary to issue weather warnings. The decision to issue a

*JEHN, K. H.; Radio and television weathercasting—the seal of approval program after five years. *Bull. Amer. met. Soc., Boston, Mass.*, **45**, 1964, p. 489.

warning rests entirely with the television meteorologist, but he acts in close liaison with the Weather Bureau forecasters at the nearby airfield. In the summer months in Oklahoma, many people leave their television sets switched on all day. If a weather warning is to be issued, the company broadcasts what is known as a 'BEEPER' and this draws the attention of the public to the fact that a weather warning is about to be issued.

In his concluding remarks Mr. Freeman said that Television Station Oklahoma City (WKY) has a coverage over a radius of about 150 to 160 nautical miles. This is obtained through the use of 'community antennae' which in this country would be known as booster stations. These are operated in the United States on a commercial basis, the community in a small radius around the station paying a small fee to the commercial company to obtain a picture at least as good as that obtained in Oklahoma City itself. Finally, once a warning has been issued it is absolutely mandatory for the weather man to provide the public with further information about the movement and development of the storm. If the storm weakens and decays, the public must be told so and not left 'hanging in mid-air'.

Dr. Ludlam opened the discussion by pointing out that the occasional great severity of local weather in Oklahoma gives Mr. Freeman a distinct advantage. The weather is very seldom as severe in this country. Mr. Freeman tells people what the weather is. Couldn't we have more of this here? It would be interesting to know, as well, how much time Mr. Freeman gets on television. Mr. Freeman replied that he has three 5-minute periods during the morning, a 10-minute period at noon, 10 minutes at six o'clock and 10 minutes at 10 p.m., making a total of 45 minutes a day. So much interest is shown in weather in Oklahoma that commercial interests fall over each other to buy television weather time for commercial advertising. They know full well that there will be a large viewing public at the normal weather presentation times. The weather, therefore, becomes a 'saleable product.' In reply to another question Mr. Freeman stated that apart from himself he has one full-time and one part-time assistant, but he is now looking for somebody else to work full-time.

Mr. Foord, one of the weather men on British Broadcasting Corporation (BBC) Television, wanted to know something about the technical details of Mr. Freeman's presentation. Did he forecast for the entire state? How long preparation beforehand did he have? What charts were used, and how did he draw them? Mr. Foord pointed out that although many people were interested in the day's weather, time to explain this was essential and the BBC only allowed 3 minutes for the full United Kingdom forecast. Mr. Freeman expressed horror at having only 3 minutes a day, saying it certainly would not be sufficient for him. He forecasts for the whole of the state of Oklahoma and has hourly surface charts plotted, and also does 850, 700 and 500 millibar analyses. He feels that it is essential to have 4 hours of preparation for a 10-minute show, and if he cannot be on duty in time to get the 4 hours he will ask his assistant to stay behind and do the broadcast instead. He makes use of a four-sided drum on which he can draw with a felt pen and paint. The maps he uses in his presentation are: a synoptic map of Oklahoma State; a map of maximum and minimum temperatures for the State; a map of the State showing the present weather situation; and two United States maps, one showing cloud cover, and the other showing representative temperatures around the country. On this last map he draws in the surface isotherms whilst he is actually doing the presentation.

Mr. Hunt of Anglia Television said that the set-up in the United States is obviously different from that in the United Kingdom. Probably the main difference is the time aspect. Even on independent television in this country there is the problem of the national network presentations. This means that it is difficult for a regional company to insert weather forecasts or warnings; but there are signs of the beginnings of elasticity in that 'promotion periods' can be used in an emergency. These are periods between programmes for which no television advertising has been allotted and the time would normally be used for 'trailing' other programmes. If the weather situation warrants it, the company will allow Mr. Hunt to make use of one or more of these promotion periods.

Professor Sheppard, Head of the Meteorology Department at Imperial College, spoke next. He was severely critical of the methods of weather presentation on television in this country at the present moment. Isobaric charts are definitely not the answer. He felt sure that the time has come when the BBC and Independent Television, if they were approached, would probably be ready to be impressed by new methods of presentation.

An animated discussion ensued on this point until, finally, Mr. Harding, Assistant Director (General Services) at the Meteorological Office, put the case for the Meteorological Office and the BBC. Admittedly the time allotted to weather forecasts on television is very limited, but the BBC is fully alive to the interest taken in the weather by people in this country and allocates about 100 minutes a day to weather bulletins on the various sound radio channels. Experience has shown that lengthy forecast bulletins encourage padding of the forecast with inessential material which results in consequent confusion to a majority of viewers and listeners. Mainly at the instigation of the BBC, individual bulletins are shorter now than they were a few years ago; this encourages clear concise forecasts. Mr. Harding was convinced that this was good policy. The BBC and the Meteorological Office have the problem of catering for those who are only interested in knowing whether it is going to rain tomorrow and would be happy with, for example, a mere simple caption chart on television, and, at the other end of the scale, for those specialist viewers such as farmers and sailors who are so very dependent on weather. The latter are extremely interested in synoptic developments, can interpret weather charts and are much more understanding of the reasons why a forecast may have gone wrong; their numbers are growing daily.

Dr. Ludlam then closed the discussion by thanking Mr. Freeman for his very interesting talk and also thanking everyone who had taken part. He regretted that there was no time left for a further film to be shown, but pointed out that the fact that he had been obliged to forcefully close the discussion showed what a lively interest had been taken in the subject.

N. ELLIS

METEOROLOGICAL OFFICE NEWS

Dr. G. B. Tucker, a Principal Scientific Officer in the Dynamical Climatology Branch of the Office (Met.O.20), is widely known for his researches and numerous papers concerning the general circulation of the atmosphere. He has recently accepted an appointment as Assistant Director (Research and Development) in the Commonwealth Bureau of Meteorology, Australia, and will be leaving the Office in early April to take up his appointment.

We extend to him our best wishes for his success in his new and important post.

NOTES AND NEWS

Services to the agricultural community

At a colloquium given in the lecture theatre at the Headquarters of the Meteorological Office, Bracknell, on 24 November 1964, Mr. G. W. Hurst described the services provided by the Meteorological Office for the agricultural community. Extracts from the lecture and the discussion which followed are given below.

Introduction.—The Agricultural Branch exists to meet the needs of agriculture, horticulture and forestry in the United Kingdom although problems occasionally arise in other fields. However, most of the work of the Branch deals with agriculture in the broadest sense and there are few progressive agricultural organizations in the U.K. with whom there is not at least occasional contact. The most important link between the Office and agriculture is through the National Agricultural Advisory Service (NAAS) which operates under the Ministry of Agriculture, Fisheries and Food in England and Wales. NAAS has eight divisional headquarters and there are meteorological offices at three of them—Bristol, Cambridge and Leeds. Meteorological representation is desirable in principle at all the centres to complement the activities of other specialists—in entomology, pathology, husbandry, etc.—who are qualified to answer most enquiries which are submitted to the centres through county advisers. Some research is done at several of the centres but most research is carried out at the main institutes such as Rothamsted, Wellesbourne, East Malling, etc. In Scotland and Northern Ireland where NAAS does not operate, the universities and research institutes disseminate scientific and specialized knowledge to the farming community.

There are about 90 agro-meteorological stations in the U.K. and their main function is to provide information suitable for meteorological work in scientific agriculture, and a further 50 establishments, including for example research laboratories, have been actively in touch with the Branch.

Routine services.—These can be divided into straightforward work, such as extraction of data, and work based on research.

Under the first of these headings are the weekly summaries of weather during the past week which are sent to NAAS and some other bodies. The circulation is about 300. Half of the summaries are prepared at Bracknell with the co-operation of Met.O.3 (Climatological Services) and half by various regional stations, roughly for their own regions.

Routine services developed from research are mostly seasonal and chiefly for the summer months. Research on some problems has led to the establishment of very definite rules of behaviour and the formulation of warning schemes, for example potato blight and apple scab warnings.

Potato blight.—This is a fungoid disease, and work done by the Office in collaboration with research stations such as Rothamsted has established that high temperatures and high relative humidity are conducive to the build-up of the fungus on the haulms. It is particularly important to carry out preventive spraying before the first outbreak.

Apple scab.—The spores causing this disease are present on fallen infected leaves. Wet conditions, during and after rain for example, can discharge the spores, and relationships have been established between the discharge and the number of hours when the trees are wet, coupled with the temperature.

Liverfluke.—This is a serious disease of sheep. The life-history of the fluke is very involved partly because the fluke necessarily spend one stage of their life-cycle in a particular species of snail; moisture is important as in very dry weather the snail population is low and the egg hatch mortality of the fluke is high. Returns of rainfall, rain days and transpiration are made monthly to the Central Veterinary Laboratory, Weybridge, and these enable a decision to be made on the necessity for 'drenching' and the application of molluscicide. It is interesting to note that when the disease is prevalent the loss to the farming community could be of the order of a million pounds in the year so that even a saving of about 20 per cent due to good advice would represent a very real profit to the community.

Potential transpiration.—Monthly potential transpiration over the country has been related to sunshine, and relevant figures are issued monthly with the routine summaries and also to other interested people. These figures assist in scientific irrigation which is particularly important in horticulture.

Non-routine services.—These cover a wide field and although many of the problems are channelled through NAAS, some are received direct. Information supplied varies from relatively simple extraction of data to a considered professional opinion based on long experience, and sometimes experiments are specially mounted to meet the required need.

Problems which have been specially studied include: irrigation needs, which may only be of concern for two months of the growing season: shelter effects—here it is interesting to note that in the Isles of Scilly the horticultural activities are being planned on a scientific basis using ideas supplied by the Meteorological Office: land use: ventilation, for example for indoor crops: and animal comfort.

The problem of frost might involve the examination of an area with a view to planting an orchard, or a comparison of the freedom from frost in neighbouring areas.

An experiment at Manor Farm, Luddington in the west Midlands, illustrates how the problem might be tackled. Figure 1 shows the site which slopes down to the River Avon, a fall of about 60 feet; the weather station is shown at W.S. and additional thermometers were specially mounted at positions I to IV. Temperature comparisons are made in Figure 2 where the average minimum and the average weekly absolute minimum for the highest (176 feet) and lowest (120 feet) sites are shown for eight weeks following 31 March in 1950 and 1951. The estimated frequency of various degrees of frost in a 10-year period in May at the two sites is as follows:

Height of site feet	Temperature		
	≤ 32°F	≤ 30°F	≤ 28°F
	estimated frequency		
176	10.5	5	1
120	22.0	15	7

The difference between the sites is quite striking and in fact a proposed orchard was not extended down to the bottom of the slope.

Research.—During the 15 years that the Agricultural Branch has existed some problems have been solved satisfactorily enough for working rules to be laid down. Problems which have been actively studied during the last 2 years are as varied as and more numerous than those listed under non-routine services. Three examples will indicate the scope of the work.

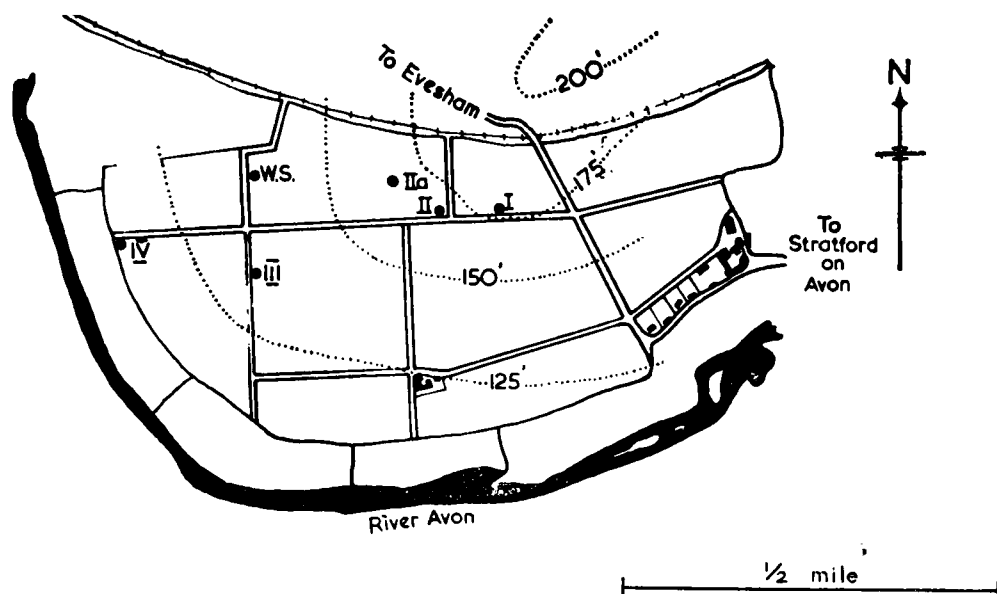


FIGURE 1—DISTRIBUTION OF THERMOMETERS AT MANOR FARM DURING A FROST INVESTIGATION IN 1950 AND 1951

W.S. is the weather station and additional thermometers were placed at positions I to IV. Contours are at intervals of 25 feet.

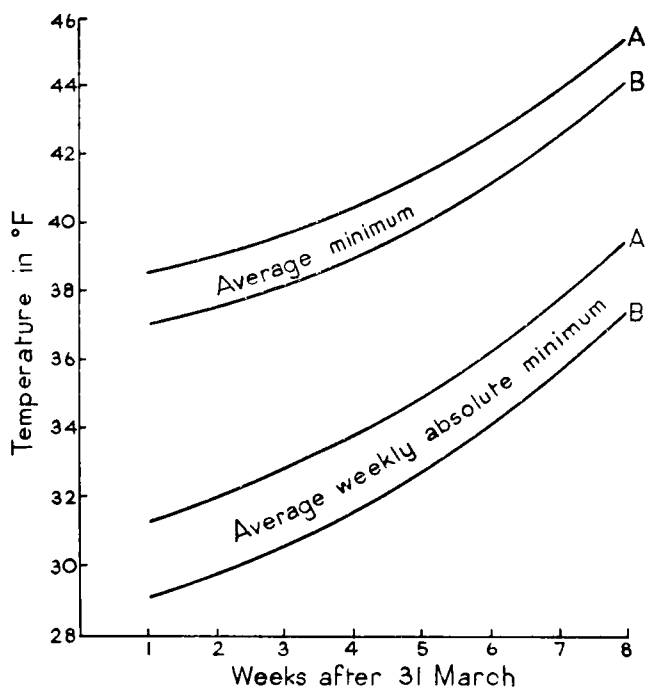


FIGURE 2—AVERAGE MINIMUM AND AVERAGE WEEKLY ABSOLUTE MINIMUM TEMPERATURE CURVES (SMOOTHED) FOR TWO SITES AT MANOR FARM FOR AN EIGHT-WEEK PERIOD FOLLOWING 31 MARCH IN 1950 AND 1951

Curves A are for site I at 176 feet and curves B are for site IV at 120 feet above MSL. (see Figure 1 for site positions.)

Sugar-beet yellows.—This disease has not been so prevalent in recent years; even so, for example, over 20 per cent of all beet plants were infected in 1961. The virus is vectored by an aphid (*Myzus persicae*) so various factors which might affect the population of this aphid early in the year were examined. It was found that correlation between incidence of the disease and rainfall and sunshine was low but the correlation was high between the temperature in February, March and April and subsequent yellows percentage. The temperature data considered were departures from average in eastern England—the main growing area for sugar beet—and the results are shown in Figure 3. The severity of an attack was assessed on a 5-point scale ranging from less than 5 per

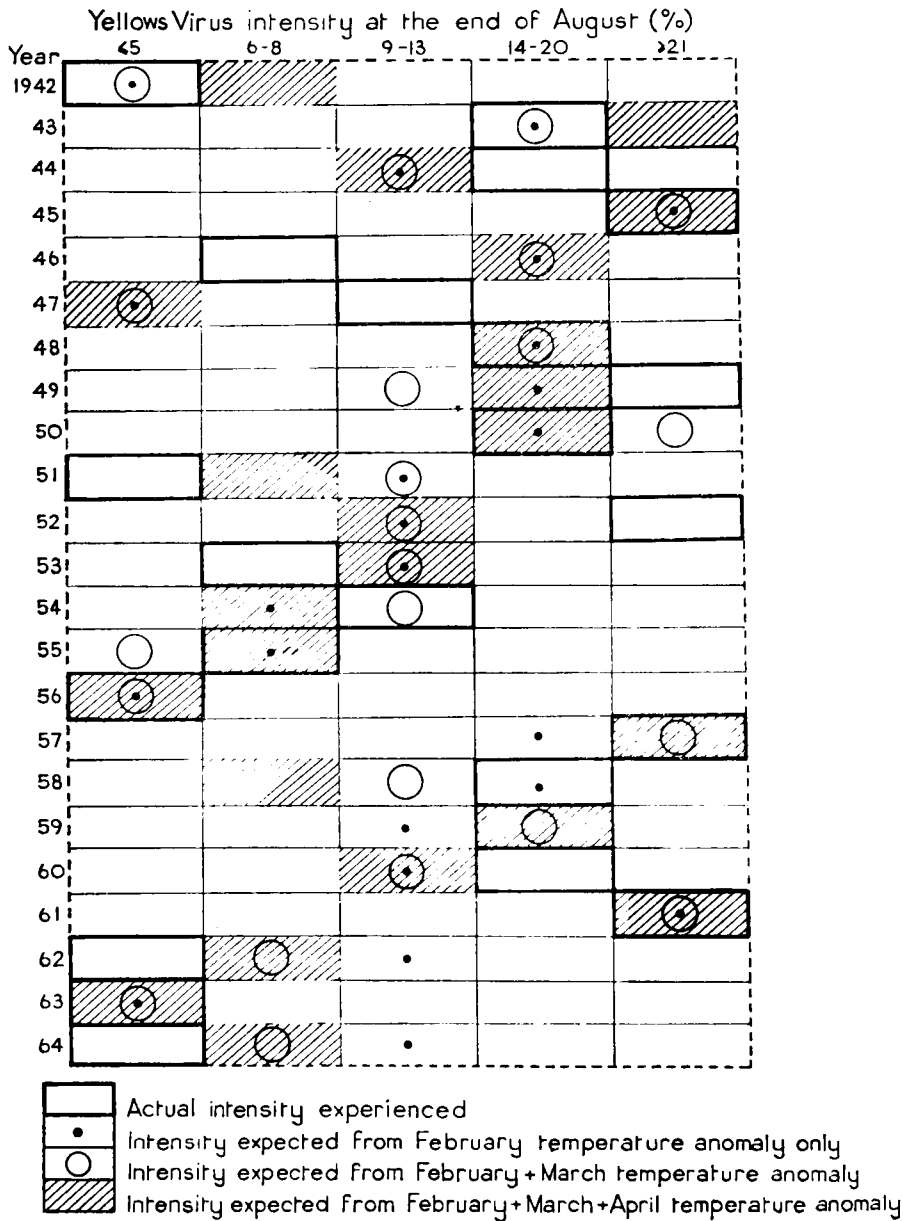


FIGURE 3—ACTUAL INTENSITY OF ATTACKS OF YELLOWS VIRUS IN THE PERIOD 1942-64 COMPARED WITH THE EXPECTED INTENSITY BASED ON TEMPERATURE ANOMALIES IN FEBRUARY, MARCH AND APRIL IN EACH YEAR

cent of yellows at the end of August in a good year to greater than 21 per cent in a bad year. Intensities expected were seldom seriously in error and in 1946, the only year in which temperature anomalies gave an incorrect expected intensity, the poor weather during May, June and July very considerably restricted the aphid numbers. The existence of the correlation of February temperature anomaly with subsequent disease is useful because during March a decision has to be made on spraying programmes for the summer. The loss of sugar from the beet can vary from 100,000 tons upwards to as much as 1,000,000 tons in one particular year—a financial loss of £5,000,000—so if the loss were reduced by 10 per cent by using good advice on the need for spraying this would represent a very real saving.

Agricultural practices.—Work has been done in relating agricultural practices in England and Wales to meteorological parameters such as effective transpiration in the summer half of the year. As an example, Figure 4 shows that far larger numbers of cattle exist in areas in the west where the effective transpiration is high than in the drier areas less suitable for grass in the east.

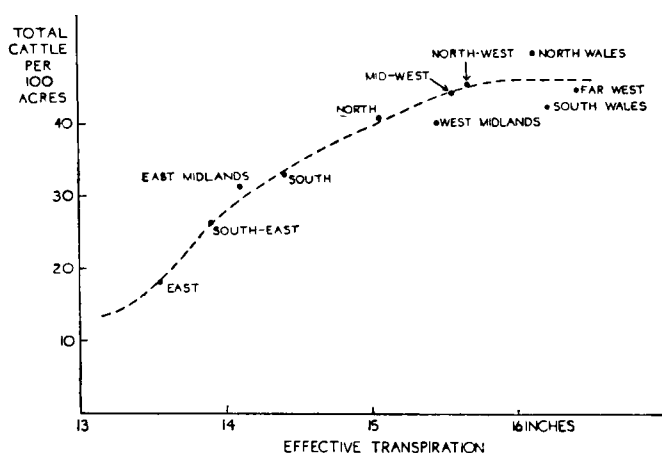


FIGURE 4—NUMBER OF CATTLE PER 100 ACRES COMPARED WITH THE EFFECTIVE TRANSPIRATION OF THE AREA

It has also been shown that the production of milk has been increasing in areas where the effective transpiration is high and decreasing where it is lower. In Figure 5 the arrows show how the percentage of national milk per unit area has changed in various counties between 1946 (blunt end of the arrow) and 1960 (pointed end of the arrow). The arrow is placed on the x-axis according to the average effective transpiration for the county. The curve has been drawn to show the 'target line' which the counties might reach. The few arrows going in the opposite direction from the expected, represent exceptional counties which may be affected by say nearness to London or communication difficulties.

Consideration of the type of crops grown compared with the soil moisture deficit at the end of August confirms the general pattern of deep-rooted crops in the dry areas and more shallow-rooted crops in the wet areas.*

Conclusions.—Future work will to some extent depend on the customers' requirements, but some of the problems envisaged concern the rational and efficient use of the land in relation to meteorological factors, control of diseases

*WALKER, J. M.; Distribution of crops with respect to mean potential soil moisture deficit at the end of August. *Met. Mag., London*, **94**, 1965, p. 18.

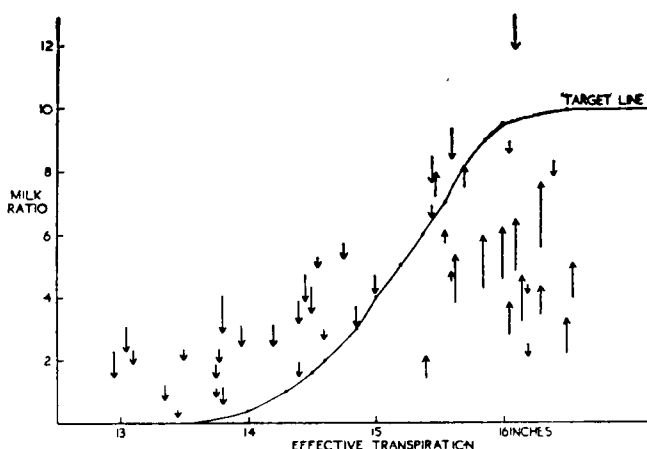


FIGURE 5—CHANGES IN PRODUCTION OF MILK PER UNIT AREA FOR THE VARIOUS COUNTIES DURING THE PERIOD 1946–60 COMPARED WITH THE EFFECTIVE TRANSPIRATION OF THE COUNTY

The blunt end of the arrow represents the position in 1946 and the pointed end the position in 1960. The 'target line' represents production figures which might be reached in time.

The milk ratio is the county production, expressed as a percentage of the total production, divided by the area of the county.

and pests, and, in the field of ventilation, the establishment of simple formulae which can be applied to the construction of animal houses, storage buildings etc. of a specific nature. In the realm of instrumentation, techniques and instruments introduced many years ago are still in use but the introduction of more sophisticated instruments including the automatic weather station can be foreseen.

Discussion.—During the lively discussion which followed, the use and meaning of grass minimum temperatures were questioned. The possibility was discussed of measuring ground temperatures over concrete rather than over grass. This would give considerably more uniform results. Soil temperatures usually fall to about halfway between the low grass minimum and the less low concrete minimum. Finding a satisfactory substitute for the grass minimum temperature would be of interest in the synoptic world as well as in agriculture.

Some discussion took place on the measurement of radiation and it was stated that a realistic network of stations giving reliable radiation measurements would be welcome.

Among other topics raised were interest in the spectrum of radiation, work for the Fisheries and the effects of air pollution.

G. W. HURST

Retirement of M. André Viaut

In October 1964, M. André Viaut, Director of the National Meteorological Service of France, retired on reaching the statutory age limit of 65.

M. Viaut is well known to meteorologists everywhere and especially to the staff of the Meteorological Office. He began his career as a professional meteorologist in 1921 and after service in France and North Africa, was appointed Director in 1945. During this period his interests lay mainly in the application of meteorology to aviation, and it is pertinent here to mention his skill as a cloud photographer. As Director, he carried out the formidable task of organizing the French meteorological service, in the years that followed the liberation,

with skill and devotion. He was appointed successively Chevalier, Officier and finally, in 1956, Commandeur of the Légion d'Honneur.

For most of us, M. Viaut is best known for his remarkable work in the international field, especially with the International Civil Aviation Organization and the World Meteorological Organization (WMO). He was one of those who formed WMO from the old International Meteorological Organization and was a prominent figure at the 1947 Conference of Directors that drew up the Convention of WMO. He was a member of the Executive Committee from its inception and in 1955 he was elected President. In 1959 he was chosen for a second term.

Those of us who attended the sessions of Congress and of the Executive Committee during the eight years of his presidency know him as a tireless worker and skilled administrator. It was largely under his guidance that WMO grew to its present position and not the least of his achievements was the successful conclusion of the negotiations with the Canton of Geneva that gave the Organization its impressive Headquarters.

No account of M. Viaut's career would be complete without referring to the help given him in the many social responsibilities of the president's office by Mme Viaut. They will be greatly missed in the meetings at Geneva.

We wish M. and Mme Viaut a long and happy retirement.

O. G. SUTTON

Appointment of M. J. Bessemoulin

We have been informed that M. J. Bessemoulin has been appointed Director of the French Météorologie Nationale in succession to M. A. Viaut, and he will also be Permanent Representative of France with the World Meteorological Organization.

We wish M. Bessemoulin every success in these appointments.

Italian Meteorological Service

Maggior Generale Prof. Giorgio Fea succeeded Brig. Gen. Fernando Giasanti as Chief of the Italian Air Force Meteorological Service on 20 January 1965. We wish Maggior Generale Prof. Fea every success in his new appointment.

REVIEWS

Meteorological soundings in the upper atmosphere by W. W. Kellogg. (WMO Tech. Note No. 60.) 10 $\frac{3}{4}$ in \times 8 $\frac{1}{2}$ in, pp. x + 48, *illus.*, Geneva, World Meteorological Organization, 1964. Price: Sw. F. 8.

The authoritative and inexpensive WMO *Technical Notes* cover a wide range of subjects. *Technical Note* No. 60, recently published, claims to present "a brief and factual review of our current knowledge of the upper atmosphere, defined as the region above the level usually attained by sounding balloons (about 30 km) and below the level of satellites (about 150 km); and it then treats the various techniques for observing conditions in the upper atmosphere." It does just that. There are six sections. In the first, the major features of the upper atmosphere are described; in the second, ground-based techniques for investigating the upper atmosphere are outlined; and in the third, fourth and fifth the uses of small meteorological rockets, of large rockets, and of guns for probing the upper atmosphere are discussed. The final chapter summarizes what

observations are most needed in order to make progress in our understanding of this region. All this is done in 23 pages yet, as is to be expected from a document prepared by Dr. Kellogg, the note is easy and pleasant to read and there are, with one notable exception, no serious omissions and nothing with which I, at any rate, can find serious fault. The omission is that there is scarcely any mention of the value of satellites in observing the high atmosphere—a strange omission since it may only be by using satellites that the world-wide cover, the importance of which is stressed in the Note, can be obtained.

There are four pages of references so that it is easy for any reader to follow up any aspect in which he is particularly interested. There are also five appendices—three of which, occupying nearly as many pages as the Note itself, serve little useful purpose.

R. FRITH

OBITUARIES

Mr. Ben. G. Brame, M.B.E.—It is with very deep regret that we heard of the death of Mr. Ben. G. Brame on 16 March 1965. A full appreciation of his many years of service in the Meteorological Office appeared in the April, 1956 issue of this magazine. Our deepest sympathy is extended to his widow in her sad loss.

Mr. R. Graham.—It was with great regret that his many friends in the Office learnt of the death of Mr. R. Graham on 25 November 1964.

'Robbie' joined the Office in 1920 as a Boy Clerk in M.O.3 which in those days included the Library as well as Climatological Services. In 1925 he moved to Renfrew and from there to Lerwick in 1928. On this occasion his stay in Lerwick was comparatively short, three years. For the next 15 years Robbie served at many outstations located throughout the United Kingdom from southern England to northern Scotland, and during this period he progressed from Boy Clerk to Assistant I and served for two and a half years as a Flight Lieutenant in the Royal Air Force Volunteer Reserve. After release from the RAFVR in 1945 he returned to forecasting duties serving at a number of stations in England and also in Italy and Habbaniya. In 1951 he entered the radiosonde field and moved to Lerwick where he stayed for the remainder of his career. Robbie had most of the qualities of an ideal officer-in-charge, always being cheerful and quite imperturbable and his work at an isolated station such as Lerwick made full use of his qualities. The long period of smooth efficient operation of the radiosonde unit at Lerwick under his guidance is a measure of his success. It was a 'happy' station and much of the credit for this was his. We extend our sympathies to his wife and family.

A.P.T.

Mr. B. K. Benfield.—We regret to announce the death of Mr. Brian Kenneth Benfield, Experimental Officer, while serving at El Adem. He was accidentally drowned at The Beach Club, Tobruk on 22 August 1964 at the early age of 29 years. During his six years within the Office he served at Little Rissington, Manchester and Liverpool Airports and at El Adem.

He impressed his colleagues by his quiet friendly nature and devotion to duty. His death is a sad loss to the Office. We extend our sympathy to his family.

W.C.D.

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NEW CRITERIA CONCERNING FINE SPELLS IN SOUTH-EAST ENGLAND DURING THE PERIOD MAY TO OCTOBER

By R. A. S. RATCLIFFE, M.A.

Summary.—From a study of 500 mb flow patterns over the years 1957–64, new criteria are deduced for forecasting fine spells in south-east England during the period May to October. The new criteria are shown to be capable of forecasting at least half of all such fine spells occurring in south-east England. Taken in conjunction with other known methods, it should be possible to forecast about three-quarters of all fine spells in south-east England between May and October.

Introduction.—Lowndes¹ criteria for forecasting fine spells have been used with success at the Central Forecasting Office for a number of years, but as Lowndes well realized, fine spells can occur with synoptic models² other than the one he chose as a suitable forecasting model.

One of the other possible ways in which fine spells occur is with an upper blocking pattern close to the British Isles. Such an upper pattern is usually slow moving and associated with a blocking surface anticyclone well north of the usual Azores position.

Both the block situation and the Lowndes fine-spell model postulate a dominating anticyclone either near the British Isles or moving north-east from the Azores region towards the British Isles.

It was noticed in 1963, when 14 fine spells occurred, that considerably less than half of these fell into the Lowndes or block categories. Further study of the fine spells of that year suggested that a third model might be found based on a strong upper flow or jet stream in some position to the north-west of the British Isles.

The purpose of this article is to define a fine-spell model in a manner which can be used by a practising forecaster without the necessity for any special charts and in as short a time as possible. Originally the new model was defined in terms of the 500 mb flow pattern. Later it was found to cover many of the fine-spell cases occurring with a strong surface ridge to the south of the British Isles when weak fronts cross south-east England without giving measurable rain.

Data used.—All the 500 mb charts for midnight in the 8-year period 1957–64 inclusive (May to October only) were scrutinized with a view to

discovering any relationship which might exist between the 500 mb flow to the north-west of the British Isles and the occurrence of fine spells in south-east England.

In this connexion, a fine spell during May to October was defined as 6 consecutive 12-hour periods in each of which both Kew and London(Heathrow) Airport were dry or had not more than a trace of rain. The 12-hour periods corresponded to the periods reported in the *Daily Weather Report*, i.e. 0900–2100 GMT and 2100–0900 GMT.

This differs from the definition of a fine spell as given by Lowndes¹ who initially used only Kew as the check station and allowed no rain to fall over the 3-day period.

Forecasting criteria.—The results of the investigation suggested the following fine-spell forecasting criteria:

The strongest 500 mb flow in the Atlantic area roughly from 40°N to 70°N, and 10°E to 50°W should be

- (i) centred inside the area bounded by 55°N to 65°N and 20°W to 40°W,
- (ii) between 180° and 270° in direction.

The strong flow may continue from approximately the same direction up or downstream outside the area of (i), the only requirement being that the core of the strong flow should be centred inside the area of (i) at some place along its length, with the following provisos:

(a) an equally strong flow from between 270° and 310° does not exist immediately upstream from the strong flow;

(b) a 500 mb trough or vortex is not in evidence near the British Isles from 5°E to 15°W including Biscay and France.

Normally the fine spell is about to begin when the criteria above are satisfied but exceptionally it may follow in one or two days.

A typical 500 mb chart illustrating the criteria is shown at Figure 1, whilst Figures 2 and 3 indicate less normal situations satisfying the criteria and followed by fine spells. Table I gives a summary of results obtained.

TABLE I—THE NUMBER OF FINE SPELLS IN SOUTH-EAST ENGLAND MAY TO OCTOBER 1957–64 AND THE NUMBER FORECAST BY THE NEW CRITERIA

Year	1957	1958	1959	1960	1961	1962	1963	1964	All years
Number of fine spells	11	10	12	10	13	13	14	14	97
Number forecast by the new criteria	7	4	7	5	8	7	6	8	52

Table I shows that over half of the fine spells occurring in 1957–64 could have been forecast using the new criteria. Lowndes¹ also states that almost half of the fine spells of 1951–58 could have been forecast by the methods given in his paper. A check on the years 1957–64 indicates that the new criteria and those of Lowndes overlap on about one third of all occasions but even so the two methods together are probably capable of forecasting about two thirds of all spells in south-east England. Some of the remaining spells occur in block-type situations and in view of the period of time for which these persist, most of them could probably be forecast. Taking the three methods as a whole it seems reasonable to state that about three quarters of fine spells in south-east England could be forecast by one or other of the three methods.

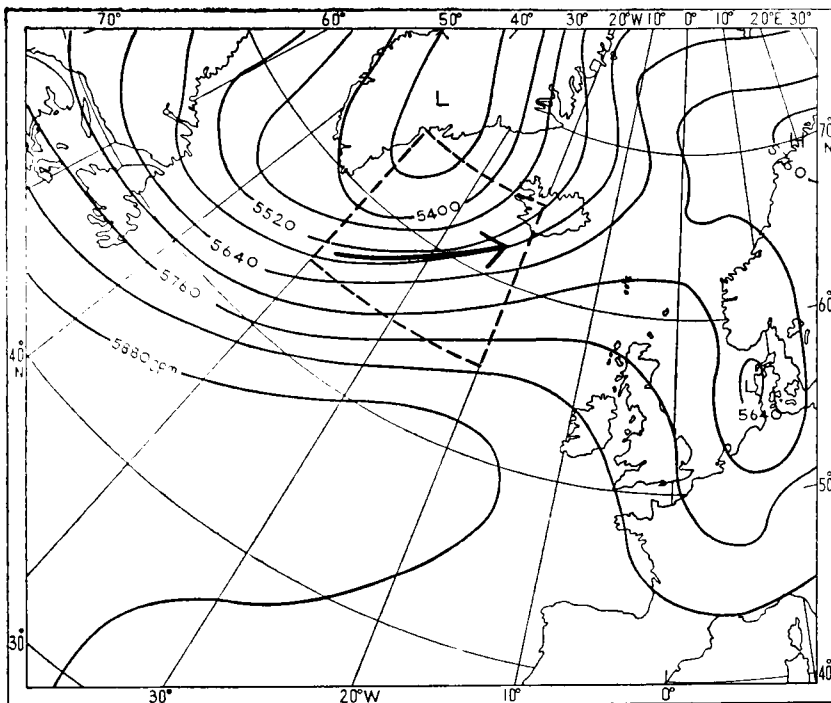


FIGURE 1—500 MB CONTOUR CHART ASSOCIATED WITH FINE SPELL, 0000 GMT,
23 JULY 1964

— — — — Boundary of defined area. Contours are in metres.
The strongest flow, indicated by an arrow, is across the centre of the defined area.

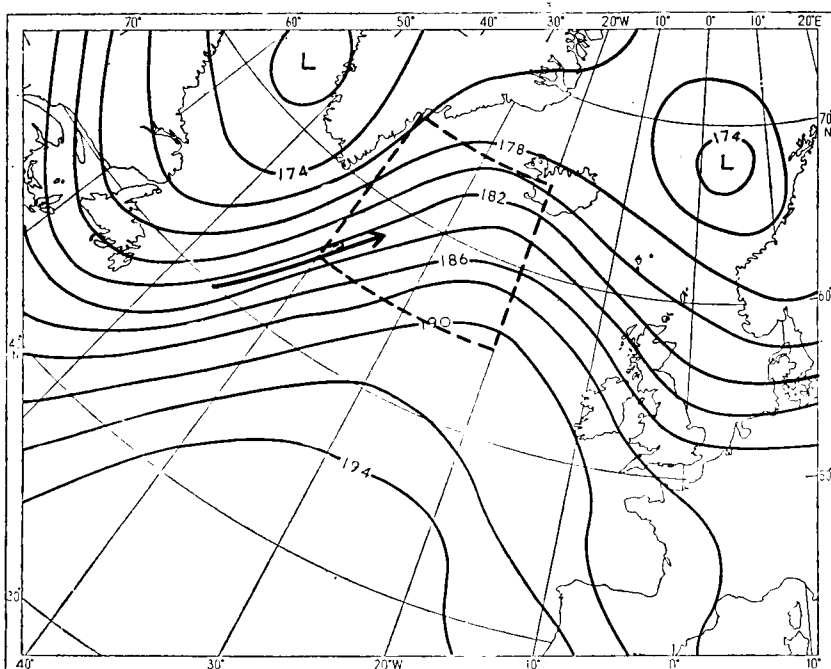


FIGURE 2—500 MB CONTOUR CHART ASSOCIATED WITH FINE SPELL, 0300 GMT,
27 SEPTEMBER 1955

— — — — Boundary of defined area. Contours are in hundreds of feet.
The strongest flow, indicated by an arrow, is near the western edge of the defined area. (Contrast with Figures 5 and 6.)

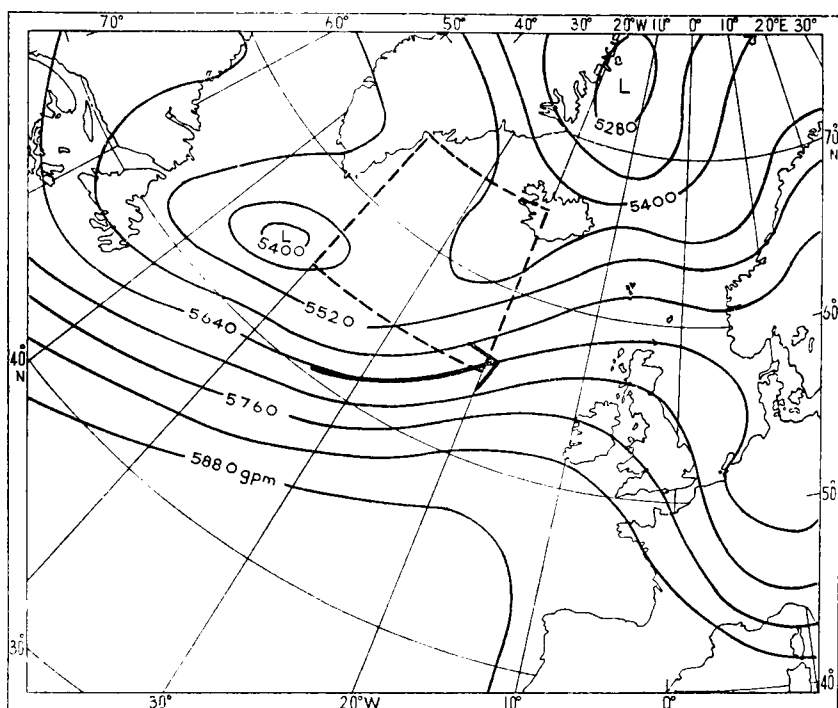


FIGURE 3—500 MB CONTOUR CHART ASSOCIATED WITH FINE SPELL, 0000 GMT, 7 SEPTEMBER 1964

— — — — Boundary of defined area. Contours are in metres.

The strongest flow, indicated by an arrow, is near the south-east corner of the defined area.

Although the new criteria are purely empirical, it is clear that they have some dynamical basis. A strong upper flow in the position indicated normally goes with a building ridge to the east and south-east and is covered by the diffluent ridge pattern of development described by Sutcliffe and Forsdyke.³ With a predominantly south-westerly flow some progression normally occurs, enabling the ridge to move towards the British Isles. But if an upper trough is between 0° and 15°W developments might spread into south-east England ahead of the ridge. On the other hand if retrogression occurs any trough between 0° and 5°E might bring rain into south-east England. Therefore in proviso (b) page 130 all cases with troughs between 5°E and 15°W are excluded (see example of retrogression in Figure 5).

Comments on the criteria.—A few more comments on the criteria seem appropriate.

(i) The exclusion of cases of strong north-westerly flow *upstream* from the south-westerly (proviso (a) page 130) is a safeguard against a north-westerly jet causing some development of the upper trough between the two strong flows. This is really covered by the initial statement that “The *strongest* 500 mb flow...” but cases of equally strong north-westerly flow *downstream* are not so important except in cases of retrogression which are discussed in paragraph (iii) page 133.

(ii) The limits of the area of the strong flow are very critical and should not be exceeded. For example a strong flow covering the whole area between 50°N and 60°N with its core at 55°N and from a direction near 270° is a very marginal

case (see Figure 4). This type of flow results in weak fronts crossing south-east England but giving only a trace of rain. Any extension of the flow further south or east, however, results in measurable rain so the forecaster should not be tempted to include cases when the flow is centred, say, at 54°N 20°W or 55°N 19°W .

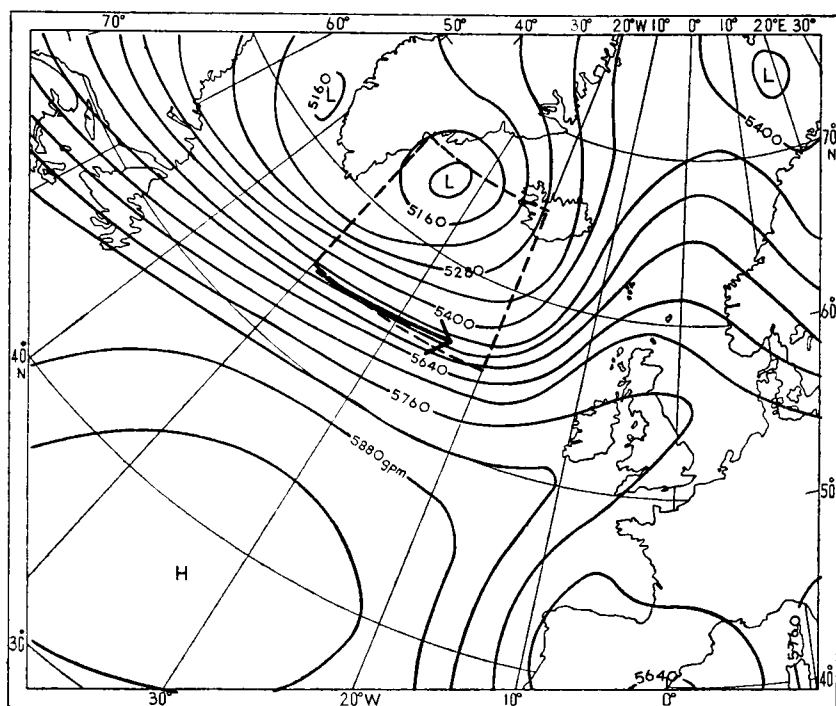


FIGURE 4—MARGINAL CASE FOR A FINE SPELL, 500 MB CONTOUR CHART, 0000 GMT, 13 SEPTEMBER 1963

— — — — Boundary of defined area. Contours are in metres.

The strongest flow, indicated by an arrow, is along the southern edge of the defined area.

(iii) Discretion is needed in cases of flow near 40°W from a direction about 180° . In these cases the long-wave pattern is probably becoming more meridional and shortening: any north-westerly upper flow over the British Isles will probably veer northerly while troughs not far away from the east coast will tend to move westwards. Figure 5 shows an example of this type of situation. It was followed by retrogression of the trough near East Anglia and no fine spell. This type is the reason for excluding occasions with a trough between 0° and 5°E . If the 500 mb pattern is clearly progressive, examples with a trough between 0° and 5°E need not be excluded.

(iv) If there is a weak trough over the British Isles and the 500 mb pattern is progressive, it is necessary to wait for the trough to clear the country before issuing a fine-spell notification. One must also re-check the flow pattern to ensure the criteria are still met at this stage. This type is more often associated with an upper flow veered from 180° and a longer wavelength than the cases in paragraph (iii).

(v) Closed 500 mb vortices near the British Isles and over France and Biscay are extreme examples of short wavelength and are often the result of retrogressive or block processes. They must be excluded. There is, however, scope

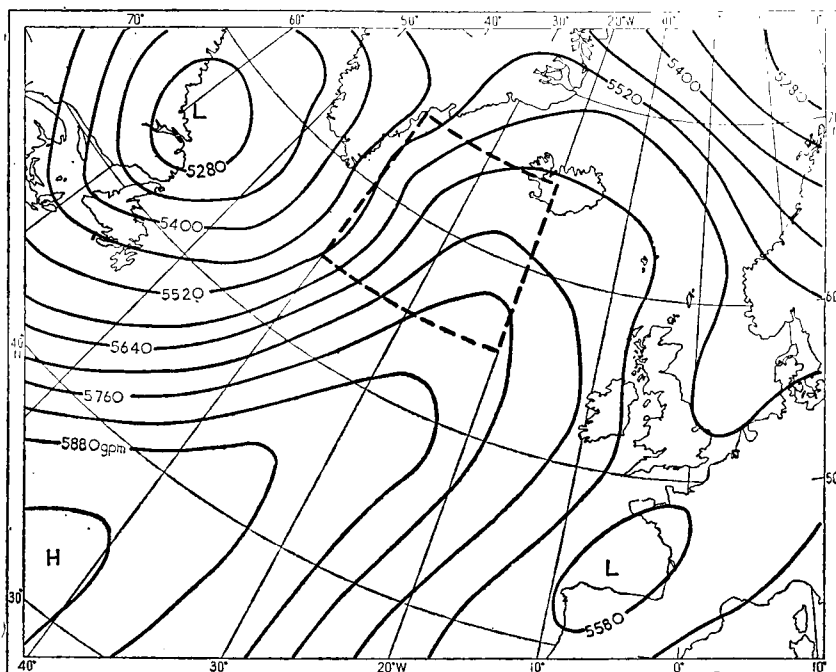


FIGURE 5—500 MB CONTOUR CHART NOT ASSOCIATED WITH A FINE SPELL,
0000 GMT, 19 MAY 1959

— — — — Boundary of defined area. Contours are in metres.
Later the trough moved further west into south-east England. (Contrast with Figure 2.)

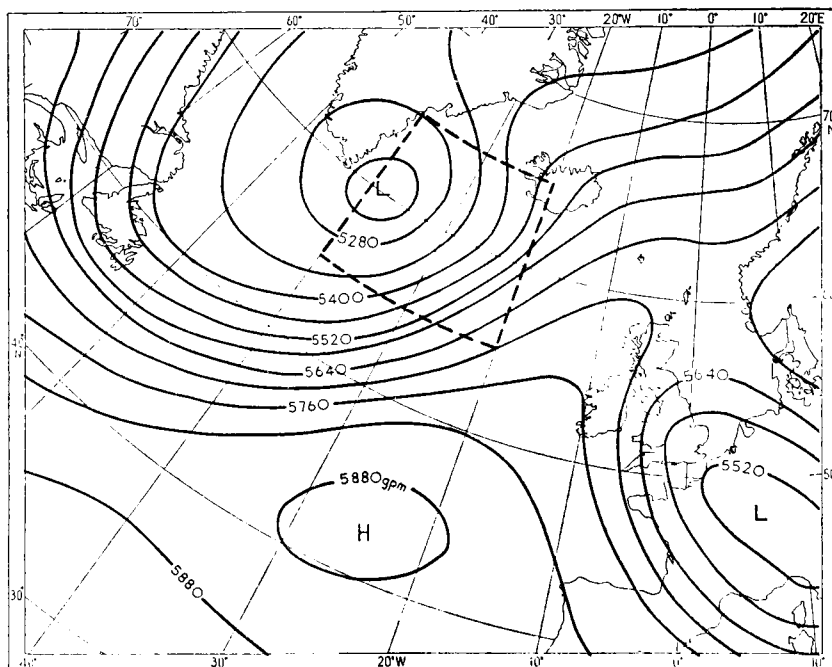


FIGURE 6—500 MB CONTOUR CHART NOT ASSOCIATED WITH A FINE SPELL,
0300 GMT, 9 JUNE 1956

— — — — Boundary of defined area. Contours are in metres.
Trough over south-east England with north-easterly winds.

for discretion in the exact limits in the positions of such vortices which merit exclusion. Cases with a 500 mb vortex over Switzerland, for example, with a trough extending back to south-east England giving north-easterly winds should be excluded (see Figure 6). On the other hand, with a weak vortex near Ocean Weather Station Kilo (45°N 16°W), issue of a fine-spell notification is justified provided the other conditions are met.

(vi) There is evidence that if there is a strong south-south-west flow near the south-west corner of the defined area (i.e. between 55°N and 65°N , and 20°W and 40°W), it is an advantage to have an equally strong or stronger flow upstream from about the same direction or only a little veered (see Figure 7). This pattern usually goes with an upper trough in approximately the Lowndes position and includes many of the cases when the two criteria overlap.

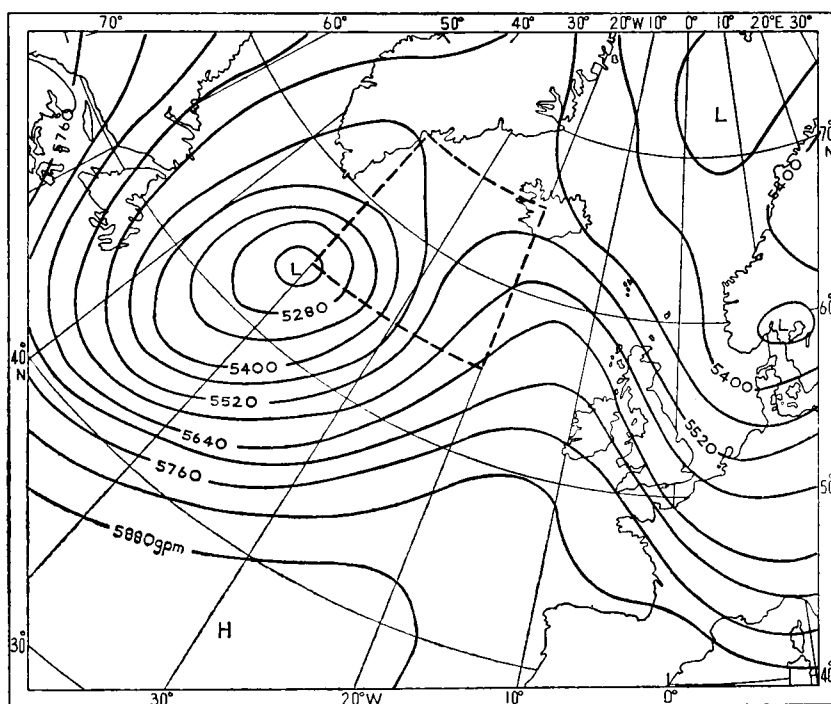


FIGURE 7—500 MB CONTOUR CHART ASSOCIATED WITH FINE SPELL, 0000 GMT, 21 SEPTEMBER 1964

— — — — Boundary of defined area. Contours are in metres.
A transition type between the 'Lowndes' model and the new model.

(vii) There are only a few occasions when the new criteria are satisfied and no fine spell occurs (see Table II on page 000). This suggests that when the criteria have occurred for several days during a fine spell *and then fail to appear*, the fine spell is likely to end within 3 days. This is only a tentative suggestion as there are cases during a spell when the criteria are not satisfied for a few days and then occur again without a break in the fine spell.

Additional tests of the criteria.—It has been shown that the new criteria can forecast a number of the fine spells which occur in south-east England. It is necessary also to show that the criteria do not occur on many occasions when there is not a fine spell. With this end in view all cases when the criteria were satisfied in the years 1957–64 inclusive were examined and tested to see whether or not they were associated with fine spells. Results are shown in Table II.

TABLE II—ANALYSIS OF FORECASTS OF FINE SPELLS 1957–64

Year	Number of days on which criteria are satisfied		Comments on failures
	with success*	with failure	
1957	26	3	26 Sept.—Followed by $2\frac{1}{2}$ dry days 25 Oct.—Last day of spell, criteria barely satisfied 28 Oct.—Strong flow from 260° between $50^{\circ}/60^{\circ}\text{N}$
1958	17	1	18 Oct.—Followed by 2 dry days
1959	46	3	24 Sept.—Fine spell followed after 3 days—criteria hardly satisfied 23 Oct.—Followed by 2 dry days 31 Oct.—Dry for $2\frac{1}{2}$ days
1960	17	0	
1961	26	2	7 July—Dry except for 0.1 mm at Kew 20 Aug.—Criteria barely met (NW flow upstream equally strong)
1962	30	3	13 May—Last 2 days of a spell 14 May—Trough just east of 5°E 9 Aug.—Definite failure—strong diffluence in flow from 260° centred $55^{\circ}\text{N } 40^{\circ}\text{W}$
1963	28	4	20 and 21 Sept.—Last 2 days of a spell 6 and 14 Oct.—Spell followed after 3 days—criteria barely satisfied
1964	24	2	1 July—0.1 mm at Kew on 3rd day 27 Oct.—Failure—trough and NE'ly flow over south- east England
Totals	214	18	Only 4 total failures

*Criteria were applied to the 0000 GMT chart (0300 GMT before 1 April 1957) for all days and were deemed to be satisfied with success if followed within 2 days by a spell as defined in the text.

There are very few cases of failure and some of these are not total failures. Six of the 18 cases of failure were followed by 2 or $2\frac{1}{2}$ dry days while 8 others occurred either on the last 2 days of a spell or 3 days before a spell began.

As a further check the criteria were tested on the independent data of 1953–56 (4 years), with the results shown in Tables III and IV.

TABLE III—ANALYSIS OF FORECASTS OF FINE SPELLS IN TEST PERIOD 1953–56

Year	Number of days on which criteria are satisfied		Comments on failures
	with success*	with failure	
1953	16	2	28 May— $2\frac{1}{2}$ dry days 21 Oct.—Last day of spell
1954	14	3	3 June— $2\frac{1}{2}$ dry days 29 Sept.— $2\frac{1}{2}$ dry days 8 Oct.— $2\frac{1}{2}$ days before a spell began
1955	33	5	9 and 10 July—Rain on the 11th at Kew only 10 and 29 Sept.—Small amounts of rain on second and third days 28 Sept.—Small amounts on one day at Kew only
1956	17	7	27 May— $2\frac{1}{2}$ dry days 31 May—0.1 mm at Heathrow on the 3rd day 10 June—Criteria hardly satisfied—flow centred $60^{\circ}\text{N } 20^{\circ}\text{W}$ 20 and 21 June—Spell 20–27 June except 0.3 mm at Heathrow on the 22nd 26 and 27 Oct.—Dry on the 26th, 27th and 29th; some rain on the 28th
Totals	80	17	

*Criteria were applied to the 0000 GMT chart (0300 GMT before 1 April 1957) for all days and were deemed to be satisfied with success if followed within 2 days by a spell as defined in the text.

TABLE IV—RESULTS OF NEW CRITERIA OVER TEST PERIOD 1953–56

Year	1953	1954	1955	1956	All years
Number of fine spells observed	11	11	14	11	47
forecast	6	6	8	6	26

Conclusions.—It is shown that it is possible to forecast about half of the fine spells which occur in south-east England by considering the 500 mb flow in the area 55°N to 65°N and 20°W to 40°W.

If this flow is south-westerly and is the strongest in the Atlantic area, then, with certain restrictive conditions, a fine spell can be forecast with a fair amount of confidence for south-east England during the months May to October inclusive.

Taken in conjunction with cases of fine spells of the Lowndes type and also blocking patterns, the three types of synoptic situation together occur with about 75 per cent of all fine spells in south-east England.

Acknowledgement.—The author is grateful to Mr. V. R. Coles, Assistant Director (Central Forecasting), for his helpful advice and criticism during the preparation of this paper.

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551.501.9:551.508.77:061

IMPROVEMENT OF RAIN-GAUGE NETWORKS

By A. BLEASDALE

Introduction.—In terms of profusion and widespread distribution of stations, rain-gauge networks throughout the world provide outstanding examples of observational networks supplying data on a regular scheduled basis. Yet, on the whole, these networks have hitherto developed in a rather haphazard manner. There are great variations and irregularities in the densities of stations, and at one end of the scale these may locally, and even regionally, reach the proportions of gross deficiencies.

International planning.—In recent years attention has been directed increasingly towards the need for the planned development and improvement of meteorological and hydrological networks in general, and of rain-gauge networks in particular. Internationally, the design or strengthening of networks has been discussed under major agenda items at a number of important meetings. These include the first session of the World Meteorological Organization (WMO) Commission for Hydrological Meteorology, Washington, April 1961,¹ the second session of the same Commission, renamed the Commission for Hydrometeorology, Warsaw, September–October 1964,² and the series of meetings held at UNESCO House, Paris, in 1962, 1963 and 1964, to prepare the programme for the International Hydrological Decade, 1965 to 1974.³ Guidance material on networks prepared by Working Groups established by the

WMO Commission, both in Washington and Warsaw, will be of great importance in connexion with some of the fundamental work to be carried out as part of the programme of the International Hydrological Decade, especially under the two headings of 'basic-data collection,' and 'representative and experimental basins.'

A further substantial contribution to the discussions at international level is being organized jointly by WMO and the International Association of Scientific Hydrology. This will be in the form of an International Symposium on the Design of Hydrometeorological Networks, to take place in Quebec City during June 1965. Preparations for the Symposium offer a suitable opportunity for reviewing the factors which are, in effect, enforcing a fresh appraisal of the problems of network design, and the requirements which must be met before general principles of design can in fact be put widely into practice.

Developments in the United Kingdom.—Nationally, in the United Kingdom, the most important recent developments which have helped to focus attention on networks, in particular rain-gauge networks, have been as follows:—

(i) *Basic data; countrywide networks.*—

(a) *For England and Wales*, the Water Resources Act of 1963, with some of the preparatory reports and other material leading up to it.

Before the Act came into force many aspects of drainage and river management, but not so much water conservation, had been the responsibility of the river boards, covering virtually the whole of England and Wales, which had been set up by the River Boards Act of 1948. From 1 April 1965, the river boards were replaced by river authorities. The functions of the new authorities relate fully to water conservation as well as river management and are not simply a transfer and continuation of the functions of the river boards but a significant extension and reinforcement of previous responsibilities. A central authority has also been established in the form of the Water Resources Board, "charged with the duty of advising river authorities with respect to the performance of their new functions."⁴ In the present context it is of particular interest to note the strengthening of the *statutory* obligations, taken over by the river authorities, to prepare and put into operation hydrometric schemes for the collection of basic data, including rainfall and now even evaporation among other elements.⁵

(b) *For Scotland*, special consideration, started by the Advisory Committee for Meteorology in Scotland, of the problem of improving rain-gauge networks in the more difficult parts of the country.

(c) *For Northern Ireland*, general improvement of climatological and rain-gauge networks, initiated several years ago, but furthered especially by the opening of Meteorological Office, Belfast, in 1960, and by the activities of the Committee on Water Resources in Northern Ireland, since it was set up in 1961.⁶

(ii) *Experimental areas.*—The establishment in 1961 of the Committee on Hydrological Research, and under this Committee, in 1962, of the Hydrological Research Unit, has stimulated experimental work, by the Unit and by other organizations, and has thereby provoked increased attention to the planning

of networks for experimental areas. A particular aspect of very special interest is the problem of providing dense networks in difficult terrain within which, because of topography, afforestation or other causes, there are few, if any, conventionally satisfactory observational sites. The Water Resources Act is important for this item too. Under the heading "Financial Provisions," specific mention is made of contributions by the Water Resources Board towards the cost of experimental work carried out by river authorities.⁷ To a limited extent some of the former river boards had already established experimental areas, even without this form of central support.

(iii) *Networks for special purposes, notably flood warning systems.*—In line with the generally increased interest in hydrological forecasting on the international scale, there has been an increase of activity in the United Kingdom with regard to flood warning systems, especially since the very wet autumn and winter of 1960–61. These schemes were developed for many areas in England and Wales by the engineers of the former river boards and will be continued and further developed under the new river authorities.

(iv) *The British Committee for the International Hydrological Decade.*—This Committee, set up in 1963, had prepared, by the end of 1964, a British programme for the Decade which to a large extent overlaps with, and is intended to stimulate, activities under items (i) and (ii) above.

Rain-gauge networks.—The haphazard development of rain-gauge networks in the past has been determined very largely by two factors:

(i) There is a need to find satisfactory sites where rainfall measurements will not be subject to systematic errors due, for instance, to over-exposure of the instruments to strong winds, over-shelter by nearby obstructions, or locally peculiar rainfall distributions caused by persistent eddies in the immediate neighbourhood. The conventionally good rain-gauge site is usually supposed to be representative for a fairly large area, and is not intended to provide information about local peculiarities. But in certain types of terrain strict observance of the conventions imposes a bias on rainfall sampling which can leave substantial gaps in the network and in knowledge of rainfall distributions.

(ii) There is also a need to find good observers, often voluntary, living or working within fairly easy reach of all selected sites. The existence of recording rain-gauges in a great variety of types, has not so far provided any widely practicable alternative to the need for local observers, though many investigators in the field, approaching rainfall work for the first time, assume that a suitable automatic recorder must have been devised long ago. In fact most if not all recording rain-gauges which have so far been produced require much more attention than the simple standard gauge used for daily readings. Recording rain-gauges at present available are not, in general, fully automatic gauges which can be left unattended for days, weeks or months at a time, to function satisfactorily without frequent servicing, and to record all the detailed information which may be needed.

Instruments and techniques for measurement.—The demands for improved rain-gauge networks, based on sound principles of network design and no longer overwhelmingly influenced by accidental circumstances, are

becoming ever more insistent as a result of the recent developments outlined. In order that the demands may be met, in any full sense, there is a need to solve the two major problems implied in the above discussion of the limitations which have been imposed, up to now, by site and observer requirements; the two developments envisaged are:

(i) Techniques of rainfall measurement and instruments will need to be developed to the point where it will become possible to measure rainfall fairly accurately over a wide variety of sites other than conventionally acceptable sites which now predominate with relatively slight variations and departures from orthodox standards. In particular, there are investigations of undoubted importance requiring the measurement of rainfall in wind-swept localities, on steep slopes, including those which face the prevailing rain-bearing winds, and at points well removed from the immediate neighbourhood of the ground, especially above canopy level in forests.

(ii) Fully automatic rain-gauges will need to be developed, primarily with the object of obtaining instruments which can be left alone on remote sites for long periods, storing rainfall data with any degree of detail which may be required. Once such an instrument has been successfully produced it is likely to be used in fairly large numbers in sparsely populated areas. But it may also have an application in other areas as an alternative to earlier types of rain recorder. These usually record in ink on paper charts, producing a form of trace which is very tedious to analyse and tabulate with all the detail which may be of interest. The new instrument would therefore be doubly satisfactory if it could take the form of a fully automatic recorder, which would operate with the minimum of servicing and attention and record the data, probably most conveniently on magnetic tape, in such a way that the information could be either directly dealt with by a computer, or readily converted for computer input.

Problems of flood warning schemes.—The use of rainfall data in connexion with flood warning schemes raises problems of a rather different kind which merit special discussion. A meteorological service can offer information of two kinds to assist in such work:

(i) An assessment of the condition of a drainage area, which will indicate the degree to which a flood risk exists. One useful way of doing this is to estimate the areal soil moisture deficit at fairly regular intervals and keep account of the decrease of the deficit under the influence of autumnal and winter rain; or, when appropriate, to estimate the water equivalent of snow lying and the degree to which this represents a danger in the event of a rapid thaw.

(ii) An assessment of precipitation or, where appropriate, of the rate of melting snow (possibly, in some cases, both).

To meet the first of these requirements, the Meteorological Office has issued, for some time past, a series of maps of estimated soil moisture deficits or, in early 1963, of the water equivalent of snow lying. Although these maps are on a very small scale and capable of substantial improvement when resources permit, their value has been clearly demonstrated through a range of conditions, and the desire for a continuation of this service has been emphatically expressed by river authority engineers and others who make use of it.

To obtain the maximum benefit from the information, however, it must be complemented by information of the second kind. Ideally this should take the form of reliable quantitative forecasts, so that the effect of meteorological conditions on river flows could always be foreseen well in advance. Partly to this end, research on the quantitative forecasting of rainfall is now being intensified.

In the meantime, confining attention to rainfall and omitting, at present, occasions of melting snow, the next best method of providing the necessary information is to arrange for the very rapid transmission of actual rainfall observations to a suitable centre established for flood warning purposes. Various arrangements have been made to achieve this end, and even now the services of voluntary observers who are often willing to make readings for little or no reward at any time of day or night are by no means negligible. But a serious difficulty is that, as with rain-gauge networks in general, a significant proportion of the rainfall readings should come from as far upstream as possible, from the hills where the main stream and its tributaries rise. In such country it is often difficult to find observers suitably situated and therefore, for this purpose also, some form of automatic instrument is an urgent requirement.

In this case, however, the instrument should be designed primarily with the object, not of storing the rainfall information in considerable detail for all periods of rainfall, light, moderate or heavy, but of transmitting in some way, as soon as possible, the significant recent information during periods of heavy rain.

Necessary development work.—Underlying current discussion of rain-gauge networks, there are therefore at least three contributory topics concerned with fields of investigations in which satisfactory results must be obtained before general principles of network design can be widely applied in any realistic sense:

(i) Development of methods of measuring rainfall within acceptable limits of accuracy on a wide variety of sites which at present are usually regarded as unsuitable for conventional rain-gauges.

(ii) Development of a fully automatic rain-gauge which unattended will store rainfall data over long periods in a form which can later be analysed with any required degree of detail by computer.

(iii) Development of an automatic rain-gauge which will be capable of transmitting recent information, especially about heavy rain, to an appropriate centre established for the operation of a flood-warning scheme.

All three items are currently receiving attention in the Meteorological Office, and, in particular, promising stages have already been reached with automatic instruments.

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551.508.77

NEW METEOROLOGICAL OFFICE RAIN-GAUGES

By A. L. MAIDENS

Interest in the measurement of rainfall is of a very long standing and has led to the design of a great variety of rain-gauges. By far the larger number of these designs have not been followed by repetitive manufacture or accepted in recognized networks of rainfall observing stations, but even so the diversity of types in regular use is considerable. Variations in the rain-gauges employed are found not only between one meteorological service and another, but also within a single service, the Meteorological Office itself currently finding it necessary to employ eight differing types to meet its various requirements.

The meteorologically most significant features of any rain-gauge are the area over which the sample of rainfall is collected, the height above ground of the rim defining this area and the outside shape of those parts of the rain-gauge which may extend above ground level. Any variations in these features will affect the aerodynamics and hence the sampling qualities of the gauge and may lead to inconsistencies in the comparative accuracy of measurement between the differing gauges. A single universal design for at least the upper part of the rain-gauge has obvious merit, but this is not easy to achieve when other important factors are considered. A major consideration is that while a gauge of large collecting area is essential when the recording of small increments of rainfall is desired, the larger the gauge the more expensive it is to construct. In consequence, the large gauge, although justified for certain applications, cannot be used as widely as may be desired and a smaller variant is thus unavoidable.

Whatever the dimensions chosen for the gauge, precautions must be taken against gains or losses of water by splashing, flooding or evaporation and against possible damage or loss of observations during periods of frost.

The standard forms of rain-gauges in universal use can be considered in three classes: (i) those which store the collected rainfall sample for short periods, (ii) those with specially enlarged storage capacity for operation over weekly or longer intervals, and (iii) those which record the rainfall at the time of occurrence.

The gauges of each class in current use by the Meteorological Office are constructed principally of sheet copper, the casings of each type being specifically designed to house one particular form of storage capacity or recording mechanism, with little or no tolerance for variations. The use of copper is itself far from ideal. It is a material of steadily increasing cost and its high thermal conductivity leads to increased internal temperatures by day, with consequential evaporation losses, and to the deposition of dew by night. Any internal heating is rapidly dissipated. During the life of the gauge the surface finish varies from a

high polish, with low radiation absorption and rapid run-off of water over the internal surfaces, to a dull matt appearance of markedly deteriorating characteristics.

The conservation of water resources as a major problem on both national and world-wide scales has led to renewed and extended interest in assessing rainfall distribution in great detail. The vast volume of rainfall measurements necessary to provide the desired density of observations can be achieved only by the employment of all possible aid from modern methods of recording and data handling, in certain cases associated with the immediate transmission of information over considerable distances.

The variety of rain-gauges necessary to provide these facilities could well add considerably to the current diversity of design, should each new requirement be treated individually. It is therefore opportune to review the whole range of current and potential rainfall measurements, to ascertain whether these may be met by a very limited number of designs which, while conserving the essential meteorological and aerodynamic similarity as to outside profile, will allow the greatest possible flexibility as to the methods for measuring, recording and transmitting the measurements.

The Meteorological Office has now completed such a study and has designed a range of components from which a variety of differing assemblies can be made to meet all foreseen requirements. This rain-gauge 'system,' which has still to be manufactured in quantity and assessed in field trials, is believed to be unique.

The casing of the complete rain-gauge assembly is made up of two components, the upper of which forms the whole above-ground profile of the gauge and thus is the more critical in regard to comparative measurements. This component includes the rim, funnel and an outer skirt. Economic considerations have dictated that two sizes shall be available, the larger, providing a catchment area of 750 cm^2 , being employed when the highest accuracy is justified, the smaller, of an area of 150 cm^2 , being a considerably cheaper variant primarily for widespread use for 12-hour or daily totals. The corresponding diameters of the two gauges are 12.2 and 5.5 inches respectively. Both upper components have in common a rim height of 30 cm above ground level, and an identical diameter at the lower skirt. The material to be used for this part of the rain-gauge has not been finally decided, but could well be fibreglass or plastic-coated metal.

Either size of catchment may be used with a single form of tipping-bucket mechanism, which is attached direct to the outlet pipe of the rain-gauge funnel. When used with the larger of the two catchment areas, an electrical impulse is obtained for each rainfall increment of 0.2 mm. With the smaller, the increments are of 1 mm.

Two forms of the base for the rain-gauge will also be available, either base being usable with either upper component. The smaller base will be cylindrical and will provide a housing for a commercial 2-litre bottle. Used with the catchment area of 150 cm^2 , this will provide storage for the equivalent of 133 mm of rainfall. Any excess up to about 4 litres (270 mm rainfall equivalent) will be retained for measurement in the base itself, which will be mounted for

easy removal within a buried section of iron or earthenware pipe. This base may also be employed merely to position the rain-gauge when used with the tipping-bucket mechanism alone, without any storage bottle.

The larger base is in the form of a substantial rectangular box with removable lid. For one application this is intended to house a large inner tank, probably of plastic, the assembly being used with the smaller catchment area as a long-term collecting gauge. In this event the quantity of rainfall will be determined by weighing the tank complete. Alternatively, it may contain recording or telemetry equipment, applicable to unattended rain-gauges in remote locations. In this application the size of funnel employed is chosen in relation to the rainfall increments desired.

In both sizes of base, provision will be made for the drainage of water passing through the tipping-bucket mechanism and for the exit of the cables for distant reading. The choice of material for this part of the rain-gauge is not critical, providing it is sufficiently strong and free from corrosion.

To provide uniform conditions in regard to the splashing of rain from ground level, the gauge will be provided with a corrugated rubber mat which will cover the lid of the larger base and any ground which may have been disturbed. For use where long-term unattended recordings are required, a magnetic tape recorder is being developed. This is housed in the larger base and will provide records of up to three months' rainfall, the tape subsequently being processed centrally by a special translator unit. Various forms of telemetry, for interchangeable employment, are being developed.

A standard form of low-voltage operated heater and thermostat will be provided to avoid frost damage or freezing of the working mechanism. It should be understood, however, that the gauge is not intended for the measurement of melted snow, nor would the heat supplied be sufficient to melt it for this purpose, except in the event of light falls.

It cannot be emphasized too strongly that none of the components described above are as yet in regular production. One form of telemetry and a tipping-bucket mechanism has been manufactured in small quantities for trial use with standard Meteorological Office 5-inch rain-gauges and, if successful, can be applied to the new system with little or no change. These two components are described in greater detail in the following article.

551.508.77:621.398

TELEPHONE INTERROGATION OF RAIN-GAUGES

By C. E. GOODISON and L. G. BIRD

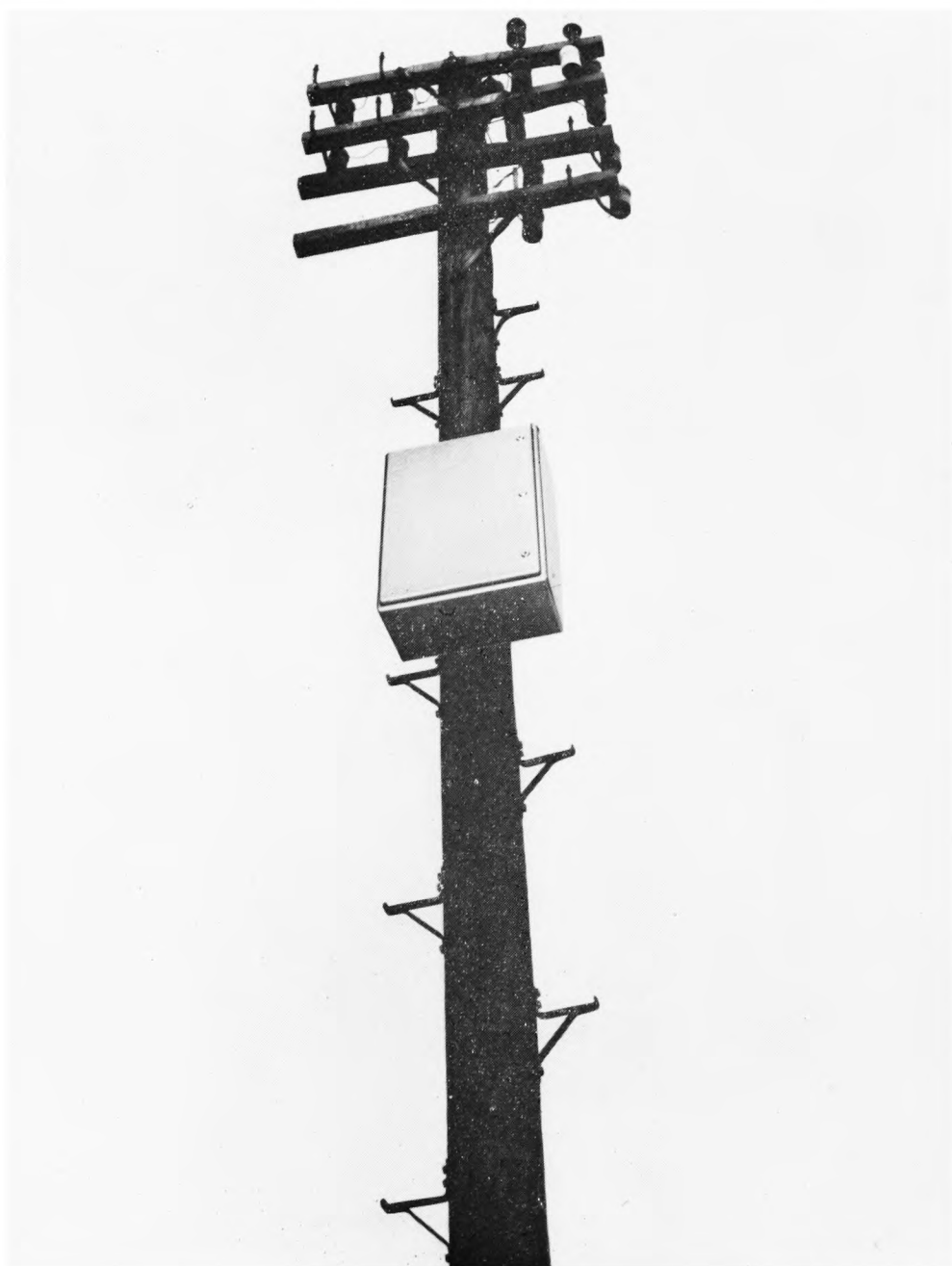
A comprehensive system for the measurement of rainfall requires that readings should be readily available from remote areas. Facilities are therefore required for telemetry over long distances using for instance a public telephone network. Such equipment has now been developed by the Meteorological Office and is in commercial production. At present the design is associated with a standard Meteorological Office 5-inch rain-gauge into which is built a tipping bucket which measures increments of 1 mm of rainfall. Only slight modifications would be necessary to adapt the design to other sizes of collecting funnels.

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PLATE I—PRE-PRODUCTION MODEL OF TELEMETER
See page 146.



Crown copyright

PLATE II—TYPICAL INSTALLATION OF RAIN-GAUGE TELEMETER
See page 147.



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PLATE III—HONG KONG'S ROYAL OBSERVATORY AS IT IS TODAY CONTRASTING
AGAINST THE NEW BLOCK OF FLATS IN URBAN KOWLOON
(Official photograph issued by Government Information Services, Hong Kong.)



Crown copyright

PLATE IV—TYPHOON WARNING SIGNAL BEING HOISTED IN THE OBSERVATORY
GROUNDS IN HONG KONG

Visual signals at 34 designated points around the Colony indicate the probable strength of a typhoon, the direction and proximity to Hong Kong. The particular signal being hoisted here is the Number Ten symbol, used to denote hurricane force winds. (Official photograph issued by Government Information Services, Hong Kong.)

The problem of measuring rainfall, as with any other accumulating quantity, is to decide whether the measurement should be made in terms of small increments (requiring a digital measuring system) or whether the sample should be stored and continuously measured as it is collected (requiring an analogue measuring system). The disadvantage of the continuous measurement method is that it must be interrupted when the storage capacity reaches its limit.

The tilting-siphon rain recorder is an example of the analogue measuring system and is inconvenient for telemetry applications because transmission of analogue information is more liable to errors than transmission of digital information. Rainfall measurement produced by the long-established tilting-siphon rain-recorder cannot conveniently be converted to electrical impulses. The Instrument Development Branch have therefore designed a tipping-bucket method, in which the quantity needed to tip the bucket is itself small and the measurement can be made in terms of the number of completely filled bucket units.

A dry-reed relay switch is used to sense each movement of the bucket. The dry-reed relay consists of two leaves of springy ferrous metal with plated contacts of precious metal. These leaves are sealed in a small glass tube filled with an inert gas. When the leaves are brought within the influence of a magnetic field, north and south poles are induced in the two separate leaves and they are brought smartly together. Removal of the magnetic field allows the contacts to open. The hermetic sealing of these relays ensures that the contact surfaces have almost unlimited life and a normal reed relay operated at its specified current load will have a life of 100 million closures.

The reliability of the magnetically-operated relay used in conjunction with the tipping-bucket gauge is much better than the reliability of the mercury switches which were previously used, and in addition the load on the tipping mechanism is much reduced.

With this tipping-bucket unit, the total rainfall is represented by the number of electrical impulses received. These may be translated by the use of a counter to provide a very simple distant-reading device as might be used between an instrument enclosure and a meteorological observing office.

The same type of rain-gauge may be used as the input to a telemetry equipment which may be interrogated by telephone as frequently as desired. The automatic gauge is provided with a telephone connexion which is allocated a 'private subscriber's' number. This number is dialled from an 'operations room' as if an ordinary telephone call were being made. The amount of rain collected since the counting mechanism of the gauge was set to zero is then transmitted in increments of 1 mm by three groups of audible tones, the groups representing hundreds, tens and units. The number of tones in the appropriate group gives the number of hundreds, tens or units. When the gauge is next interrogated, say after an interval of three hours, a simple subtraction gives the amount of rain that has fallen during the period.

Rates of rainfall may be deduced by careful choice of the frequency of interrogation and the duration of rainfall may be determined to within close limits. The gauge could be one of a network sited in the catchment area of a river.

Description of equipment.—The rain collector is a 5-inch rain-gauge in which the rain is made to operate a tipping bucket as shown in Figure 1. With the bucket in the position shown, rain falls from the funnel into compartment A until the bucket overbalances and takes up the position shown by the broken outline. As the bucket moves, the magnet B passes close to the reed switch C and causes the switch contacts to close briefly. The contacts are released as the magnet moves to D. Rain then falls in the compartment E until the bucket tips and returns to the initial position. The brief closure of the switch contacts is sufficient to operate the counting and storing relays described below, the bucket of the rain-gauge tipping once for every millimetre of rain collected.

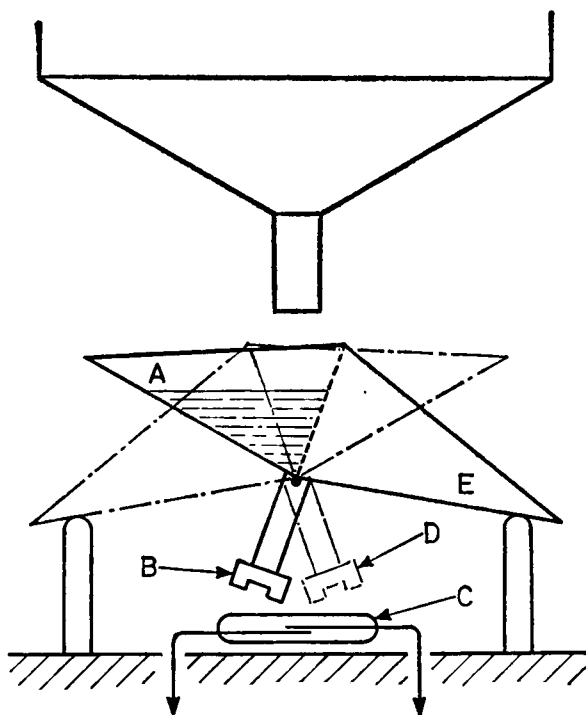


FIGURE 1—TIPPING-BUCKET RAIN-GAUGE

A and E are compartments of the bucket. The magnet B moves to position D when compartment A is full of rain and tips. C is the reed switch.

The first model of the telemeter was purely mechanical and was based on a design by E. Betz.¹ This design functioned well during initial trials but was considered unnecessarily complex for large-scale manufacture. An electro-mechanical version using standard components was developed by the Instrument Development Branch and tested over a period of six months. From this prototype six pre-production models were made under contract.

The telemeter consists of three parts; a unit for counting and storing the number of tips made by the rain-collecting bucket of the rain-gauge, a transmitter for converting the number of tips of the bucket into a number of tones in the three groups, and a station identifying and answering device (see Plate I). This last is a mandatory component whenever unattended equipment is attached to a British GPO subscriber telephone.

The counting unit consists of three relays of a special design, each counting in decades. The operation of these relays depends on the magnetic phenomenon known as remanence. With all types of magnetic materials a small amount of magnetism is left whenever they are taken through a magnetizing cycle. In these relays the remanent magnetism is enough to hold on the contact pieces when these are brought into contact with the relay core.

There are 10 contacts in each relay and, by an ingenious arrangement of springs whereby only one contact at a time is held on, the contacts are made and broken in succession. This means that when four pulses are received, then the fourth contact only will be made. If three further pulses are then added to the first four then only the seventh contact is made. This type of relay is obviously, then, an adding and storing device. When the tenth contact is reached in the 'units' relay it is made to pass a pulse to the 'tens' relay, at the same time restoring the 'units' relay to zero. When the tenth contact is reached in the 'tens' relay a pulse is passed to the 'hundreds' relay. When a total of 999 pulses has been stored the next pulse received from the rain-gauge bucket restores all the relays to zero and the counting cycle recommences.

The transmitter is basically a British Post Office type uniselector actuated by a relay and capacitor arrangement which, when scanning, allows each contact to be made in the uniselector for about half a second. As each counter relay is scanned an oscillator provides a tone lasting half a second at each position of the uniselector. Thus, if in the 'units' counter relay seven bucket tips are stored, seven short tones are passed down the telephone line. The fast switching required to operate the audio-frequency oscillator is achieved by using a trigger-controlled transistor bistable.*

The station identification unit senses the ringing tones of an interrogating call and initiates transmission of a short pre-recorded verbal identification message. This is followed by three groups of tones.

The counter store may be interrogated any number of times and the whole equipment is approved for use over the British GPO speech telephone lines. The equipment is housed in a strong, weather-proof metal box which may be easily attached to a pole or other support near the rain-gauge (see Plate II). Three months' operation should be achieved by the dry battery pack incorporated.

Other applications for the counter and telemeter parts of the system are under consideration by the Meteorological Office and by some potential industrial users. One device, under consideration by the Instrument Development Branch, will initiate a warning whenever a preset amount of rainfall has been received during a fixed period of time.

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*A bistable is a circuit which has two stable states.

ANNUAL MINIMUM AND ANNUAL MAXIMUM TEMPERATURES

By L. P. SMITH

Introduction.—Knowledge of the lowest air temperatures likely to be experienced during the year is required for such problems as the calculation of the heating needs of buildings and knowledge of the highest temperatures is used for example in the calculation of ventilation requirements. This article analyses the available data of the annual temperatures.

Data.—Over a hundred stations in Great Britain are available with records of 30–60 years during the present century. No attempt has been made to reduce these to a common period and it must be remembered that the winters of the first 40 years of this century were generally mild. Therefore the stations with the shorter period of observation, say 1920–60, are likely to indicate lower median values of annual minima than those with the full 60 years. The difference, however, is likely to be small.

Method of analysis.—

Annual minimum temperatures.—Because the range of annual minima is large and there is no obvious mode it is not easy to find a satisfactory simple method of analysis. For ease of extraction it was decided to record the median values and also the value which was only exceeded (in that temperatures were lower) 1 year in 5 (boundary of lower quintile).

Annual maximum temperatures.—Again to facilitate extraction the median values were recorded and also the boundaries of the upper and lower quintiles.

Table I gives the statistics arranged under county headings in alphabetical order. The station heights are shown and the number of years of data as well as the lowest and highest values of the annual minima and maxima, the median values and the root mean square of the variation from the median. Quintile values are given in columns headed 'seldom below' and 'seldom above.'

Discussion of the data.—Despite the simple method of treatment, certain interesting facts emerge from the minimum temperature data. The stations fall into four main groups—coastal, urban, country and hill stations. The coastal medians show considerable uniformity. In the south-west along the coast between Anglesey and Portland, the values lie chiefly within the range 27–29°F; elsewhere most coastal stations show values between 23° and 25°F. The urban stations are generally warmer than the surrounding countryside, for example Westminster, Birmingham, Sheffield and Manchester all have a median value of either 22° or 23°F. The country stations range between 15° and 20°F with the coldest areas in the east Midlands, Kent, Salisbury Plain and around Shrewsbury. The few hill stations in England and Wales, for example Buxton and Rhayader, have medians chiefly around 13–14°F and in Scotland the medians may be below 10°F (Braemar 3°F, Balmoral 6°F). If the figures are plotted on a map this gives a good general picture of the distribution of the median values but it is inadvisable to draw isopleths to represent the data as minimum temperatures are essentially a local phenomenon.

If the median values of the maximum temperatures are plotted then the isotherm for 85°F includes all stations within an approximately circular area

TABLE I.—STATISTICS OF ANNUAL MAXIMUM AND MINIMUM TEMPERATURES

	Height above msl. feet	Period of data years	Annual maximum temperatures			Lowest Root mean square†	Annual minimum temperatures			Period of data years	Lowest	Annual minimum temperatures			Highest Root mean square†
			Highest	Seldom* above	Median below		Highest	Seldom* below	Median below			Seldom* below	Median below	Highest	
degrees Fahrenheit															
ENGLAND															
BERKSHIRE															
Reading University	148	54	95	91	87	78	82	87	82	40	9	17	20	25	3.7
Shinfield	200	42	95	89	88	77	83	88	83	40	5	15	19	24	4.1
BEDFORDSHIRE															
Woburn	291	53	94	89	85	74	81	85	81	60	-5	9	16	21	6.1
CAMBRIDGESHIRE:															
Cambridge (Botanical Gardens)	41	48	96	91	87	78	83	87	83	60	1	11	18	24	5.4
CHESHIRE:															
Bidston	198	47	87	85	82	73	76	82	76	60	15	21	24	30	3.6
Macclesfield	500	49	88	87	83	74	80	83	80	60	7	14	18	24	4.2
CORNWALL:															
Bude	50	30	89	85	82	74	77	82	77	47	12	20	23	28	3.5
Falmouth	167	53	85	80	77	69	74	77	74	60	18	23	27	32	3.3
Gulval	50	31	86	82	78	73	76	78	76	35	13	24	27	32	3.9
Newquay	176	51	86	82	77	72	75	77	75	60	16	22	25	31	3.5
Penzance	55	36	85	81	78	70	75	78	75	60	17	25	29	33	3.6
GUMBERLAND:															
Keswick	254	41	91	84	82	75	78	82	78	47	0	11	18	25	5.7
Newton Rigg	560	51	87	84	81	73	78	81	78	55	0	8	13	22	5.4
DERBYSHIRE:															
Buxton	1007	53	88	83	79	70	76	79	76	60	-1	9	14	22	5.3
DEVONSHIRE:															
Barnstaple	25	20	90	87	83	77	79	83	79	60	3	17	20	27	4.0
Cullumpton	202	50	92	88	85	76	82	85	82	52	2	16	19	26	4.4
Exmouth	195	38	86	82	78	70	75	78	75	46	10	20	23	28	4.3
Ilfracombe	35	49	86	83	80	73	76	80	76	60	19	25	28	32	3.0
Plymouth	87	53	87	83	80	70	76	80	76	40	16	21	24	29	3.4
Princetown	1359	39	86	80	77	69	73	77	73	50	8	15	19	27	3.3
Torquay	27	48	87	82	79	71	76	79	76	60	16	23	26	30	3.2
DORSET:															
Portland Bill	32	50	83	78	74	67	70	74	70	54	19	24	27	32	3.0
Shaftesbury	722	56	91	85	81	75	78	81	78	60	9	17	20	25	3.5
Weymouth	16	39	90	86	81	74	77	81	77	60	16	21	23	31	3.1
DURHAM:															
Chopwellwood	446	47	88	84	80	72	76	80	76	48	5	12	18	24	5.1
Ushaw	594	47	87	84	80	72	76	80	76	60	9	15	20	25	4.1
ESSEX:															
Earls Colne	160	29	96	89	86	78	82	86	82	34	6	15	19	23	4.2
Halstead	139	45	97	90	88	79	84	88	84	57	1	11	17	25	5.8
Shoburness	11	57	92	87	83	77	80	83	80	60	9	17	21	27	3.9
GLOUCESTERSHIRE:															
Cheltenham	214	46	93	89	86	78	82	86	82	56	6	16	20	25	4.1
HAMPSHIRE:															
Bournemouth	139	54	93	87	82	76	79	82	79	56	12	18	21	28	3.4
Long Sutton	512	33	92	89	86	76	83	86	83	36	8	10	17	22	4.6
Portsmouth	7	42	91	85	81	75	79	81	79	59	12	21	24	29	3.3
South Farnborough	226	45	94	90	87	79	83	87	83	45	3.7	10	16	24	4.6
Southampton	65	54	93	88	85	77	81	85	81	59	11	18	21	27	3.6

*Seldom' = 20 per cent of occasions or 1 year in 5; the figures given are the upper and lower quintiles.

†Root mean square of the variation from the median.

TABLE I—STATISTICS OF ANNUAL MAXIMUM AND MINIMUM TEMPERATURES—*contd.*

Height above MSL feet	Period of data years	Annual maximum temperatures				Annual minimum temperatures			
		Highest	Seldom* above	Median	Seldom* below	Lowest	Seldom* below	Median	Highest
				degrees Fahrenheit				degrees Fahrenheit	Root mean square†
HEREFORDSHIRE:									
Ross-on-Wye	223	49	91	87	84	81	75	3.5	6.3
HERTFORDSHIRE:									
Rothamsted	420	58	92	88	84	80	73	4.2	4.6
ISLE OF MAN:									
Douglas	284	53	82	79	75	73	68	3.2	2.7
ISLE OF WIGHT:									
Sandown	13	52	88	82	80	77	74	3.4	3.5
Ventnor	443	57	89	84	79	76	73	3.7	4.0
KENT:									
Dover	19	50	89	85	81	77	73	4.0	3.9
East Malling	122	36	92	89	85	83	80	3.3	5.3
Folkestone	128	44	90	87	81	77	75	4.5	4.4
Margate	51	52	94	88	83	80	75	4.6	3.4
Tunbridge Wells	351	56	95	90	86	82	76	4.2	4.2
LANCASHIRE:									
Bolton	342	49	89	86	83	78	74	3.6	4.2
Manchester	125	49	91	88	85	80	74	4.2	4.3
Morecambe	23	35	89	86	81	77	75	4.0	2.1
Southport	35	52	91	87	82	78	74	4.4	2.6
Stonyhurst	377	53	86	83	80	76	71	3.7	3.9
LINCOLNSHIRE:									
Cranwell	204	39	92	89	86	81	74	4.6	5.1
Skegness	15	57	89	84	80	78	76	3.3	4.4
LONDON:									
Hampstead	450	49	95	89	85	82	76	4.1	3.9
Westminster	27	58	96	91	87	83	78	4.0	3.1
NORFOLK:									
Cromer	178	57	94	89	85	81	78	4.0	3.0
Sprowston	93	35	95	88	85	81	76	4.1	5.2
Yarmouth	5	57	89	84	79	77	74	3.7	3.8
NORTHAMPTONSHIRE:									
Raunds	213	48	98	90	87	83	77	4.1	6.1
NORTHUMBERLAND:									
Cockle Park	326	51	86	82	77	74	70	4.1	4.5
Tynemouth	95	49	86	80	77	74	70	3.3	4.2
NOTTINGHAMSHIRE:									
Nottingham	192	58	94	89	84	82	75	4.2	4.3
Sutton Bonington	157	31	91	88	85	81	75	3.9	5.5
OXFORDSHIRE:									
Oxford	208	57	95	89	86	82	75	3.9	4.0
ISLES OF SCILLY									
St. Mary's	163	53	82	76	73	70	67	3.6	2.7
SHROPSHIRE:									
Shrewsbury	184	45	93	87	84	80	78	3.6	6.5
SOMERSET:									
Bath	67	58	93	88	84	81	76	3.9	4.5
Cannington	95	29	92	87	84	80	74	4.0	5.5
Long Ashton	162	41	93	88	84	81	76	3.6	4.9
Weston-super-Mare	28	34	91	88	84	81	77	3.7	3.6

*'Seldom' = 20 per cent of occasions or 1 year in 5; the figures given are the upper and lower quintiles.
†Root mean square of the variation from the median.

TABLE I—STATISTICS OF ANNUAL MAXIMUM AND MINIMUM TEMPERATURES—*contd*

	Height above msl feet	Period of data years	Annual maximum temperatures			Period of data years	Annual minimum temperatures			Highest Root mean square†
			Highest	Seldom* above	Median degrees Fahrenheit		Lowest	Seldom* below	Median degrees Fahrenheit	
SUFFOLK:										
Felixstowe	10	55	86	82	80	78	74	2.8	38	29
SURREY:										
Croydon	220	51	95	90	86	83	78	3.7	41	26
Wisle	150	57	96	91	87	83	78	4.1	57	25
SUSSEX:										
Bognor	24	46	90	82	79	75	74	3.8	57	29
Brighton	32	50	90	86	83	79	75	3.7	52	29
Eastbourne	23	48	90	83	79	77	73	3.4	56	29
Worthing	25	46	90	83	80	77	74	3.3	60	29
WARWICKSHIRE:										
Birmingham	536	53	94	87	83	80	74	3.9	60	27
Coventry	338	58	94	89	86	81	76	4.1	60	24
WILTSHIRE:										
Porton	362	43	93	88	85	81	76	3.8	41	24
Marlborough	424								60	23
WORCESTERSHIRE										
Malvern	377	46	91	88	84	79	75	3.9	58	26
YORKSHIRE:										
Ampleforth	313	51	89	84	80	77	73	3.8	60	27
Huddersfield	762	53	92	87	82	80	74	4.4	60	23
Hull	8	59	91	87	83	80	76	3.8	60	28
Ilkley	315	28	90	85	83	79	75	3.5	37	22
Scarborough	118	57	90	84	79	77	72	4.2	60	22
Sheffield	429	53	92	87	82	80	74	3.9	60	23
Spurn Head	29	57	86	82	78	76	73	3.3	60	28
Wakefield	115	49	90	88	84	81	76	3.9	54	24
York	57	53	92	88	83	81	76	3.9	60	25
WALES										
ANGLESEY:										
Holyhead	26	57	91	81	76	73	69	4.8	60	32
CAERNARVON:										
Llandudno	13	58	90	86	79	76	71	4.9	60	28
CARDIGAN: *										
Aberystwyth	12	52	91	84	80	77	71	4.0	60	27
Aberystwyth Plant Breeding Station	452	36	88	83	80	76	73	3.8	35	26
FLINT:										
Hawarden	17									
Rhyl	31	56	91	86	81	77	71	4.3	60	26
GLAMORGAN:										
Cardiff	202	56	91	85	82	79	75	3.7	57	28
Swansea	27	51	89	84	80	78	72	3.8	48	30
MONMOUTH:										
Newport	265	41	93	87	85	81	76	3.7	43	29
MONTGOMERY:										
Welshpool	254	43	90	87	83	81	77	3.4	42	23
PEMBROKE:										
St. Ann's Head	142	51	86	79	75	72	66	3.8	47	33

*'Seldom' = 20 per cent of occasions or 1 year in 5; the figures given are the upper and lower quintiles.
†Root mean square of the variation from the median.

TABLE I—STATISTICS OF ANNUAL MAXIMUM AND MINIMUM TEMPERATURES—contd

	Height above sea- level feet	Period of data years	Annual maximum temperatures			Annual minimum temperatures			Period of data years	Lowest of data years	Annual minimum temperatures			Highest Root mean square†
			Highest	Seldom* above	Median degrees Fahrenheit	Seldom* below	Median degrees Fahrenheit	Lowest			Lowest below	Median degrees Fahrenheit		
RADNOR: Rhayader	757	37	87	85	81	78	74	3.5	37	-10	11	13	20	5.7
CHANNEL ISLANDS Jersey	273	45	96	89	83	81	75	4.4	50	17	25	27	34	3.8
SCOTLAND														
ABERDEEN:														
Aberdeen	170	53	83	78	75	73	66	3.9	58	5	14	19	27	5.2
Balmoral	927	55	88	83	78	75	71	4.2	55	-10	0	6	16	3.5
Braemar	1113	52	85	82	78	75	73	3.2	54	-13	0	3	14	5.4
Craighstone	300	36	84	80	76	74	70	3.2	35	10	15	17	27	4.3
Logie Coldstone	608	37	86	82	79	75	74	3.0	38	-10	3	7	18	6.0
ANGUS:														
Arbroath	95	41	86	80	76	73	69	3.9	60	4	15	19	27	4.7
Dundee	147	53	86	83	79	77	70	3.7	45	8	16	21	27	4.9
Kettins	222	32	86	82	78	76	73	3.4	36	-5	5	13	22	6.7
Montrose	186	33	83	80	76	74	71	4.4	59	5	16	20	26	3.9
ARGYLL:														
Oban	229	44	85	81	77	75	71	3.5	49	10	19	22	28	3.6
Tiree	29	34	79	76	72	70	64	3.7	34	20	23	25	31	2.7
AYR:														
Colmonell	170	51	88	81	78	75	71	3.6	53	5	15	18	24	4.0
Kilmarnock	115	53	90	84	81	78	72	3.8	47	0	11	18	24	5.8
BANFF:														
Banff	80	41	84	81	77	74	70	3.4	44	5	15	20	29	5.2
BERWICK:														
Marchmont	498	53	87	83	79	76	71	3.7	60	5	12	18	25	4.4
BUTE:														
Rothsay	150	51	84	80	77	72	70	3.8	59	12	22	25	31	3.4
CATHNESS:														
Wick	119	56	80	73	70	67	64	3.3	60	8	13	18	28	3.8
DUMFARTON:														
Helensburgh	293	46	85	82	78	76	73	3.0	60	7	16	19	27	4.2
DUMFRIES:														
Dumfries	140	55	91	83	80	78	73	3.6	60	5	14	18	23	4.5
Eskdalemuir	794	51	85	81	78	75	66	3.6	51	-1	7	11	23	5.0
Ruthwell	95	42	90	86	83	80	74	3.3	49	1	11	16	22	5.1
EAST LOTHIAN:														
N. Berwick	151	35	88	82	78	74	72	4.1	37	6	14	21	26	5.2
FIFE:														
Cupar	82	38	85	81	78	75	72	3.2	52	3	12	17	25	5.2
Kirkcaldy	137	40	87	83	78	75	72	3.8	43	6	14	21	27	5.3
Leuchars	35	38	84	81	77	75	70	3.5	39	10	13	19	26	4.4
St. Andrews	13	41	86	82	78	75	70	3.7	46	7	12	19	25	4.6
INVERNESS:														
Dalwhinnie	1176	28	86	83	78	74	68	4.2	30	-7	0	4	14	5.3
Fort Augustus	70	50	87	81	78	75	71	3.8	50	-1	9	14	23	4.6
Fort William	27	48	86	81	79	76	71	3.6	49	5	11	18	25	4.6
Inverness	13	43	87	81	77	73	70	4.1	58	13	13	19	26	4.5
Onich	48	36	86	82	79	76	70	3.5	35	12	16	20	26	3.3

* 'Seldom' = 20 per cent of occasions or 1 year in 5; the figures given are the upper and lower quintiles.

† Root mean square of the variation from the median.

TABLE I—STATISTICS OF ANNUAL MAXIMUM AND MINIMUM TEMPERATURES—*contd.*

Height above MSL <i>feet</i>	Period of data <i>years</i>	Annual maximum temperatures				Lowest Root mean square†	Annual minimum temperatures				Period of data <i>years</i>	Lowest	Annual minimum temperatures			Highest Root mean square†
		Highest	Seldom* above	Median below	Seldom* below		Highest	Seldom* below	Median below	Highest						
				<i>degrees Fahrenheit</i>					<i>degrees Fahrenheit</i>					<i>degrees Fahrenheit</i>		
LANARK:																
Dungavel	798	32	83	80	78	75	70	3.2	37	9	12	18	25	4.4		
MIDLOTHIAN:																
Boghall	639	25	84	81	76	75	71	4.1	36	6	14	19	26	4.6		
Edinburgh	200	47	83	81	77	75	70	3.4	60	14	19	22	28	3.2		
MORAY:																
Gordon Castle	104	52	86	83	79	77	73	3.7	60	-1	12	18	26	6.0		
NAIRN:																
Nairn	20	57	86	82	78	75	72	3.6	60	2	5	16	25	5.2		
PEEBLES:																
West Linton	800	51	89	83	77	75	70	4.4	53	-6	5	10	20	6.4		
PERTH:																
Grieff	400	34	89	82	78	76	73	3.9	37	4	13	18	25	5.0		
Perth	77	47	89	84	80	78	74	3.6	60	-7	8	13	21	6.2		
RENFREW:																
Abbotsinch	19	13	86	84	79	78	77	3.4	40	0	11	16	23	4.6		
Greenock	200	47	84	81	77	74	71	3.4	60	14	20	23	30	3.7		
Paisley	105	47	86	84	80	77	73	3.5	60	8	15	20	27	4.5		
ROSS AND GROMARTY:																
Achnashellach	220	37	88	82	79	76	72	3.5	35	3	10	15	25	5.6		
Fortrose	15	49	83	79	76	72	69	3.5	30	13	18	22	30	3.6		
Stornoway	11	57	78	75	72	68	65	3.3	60	10	17	22	28	3.2		
ROXBURGH:																
Kelso	195	44	87	85	81	77	72	3.8	60	-3	9	15	22	5.9		
Wolfelee	537	30	88	84	81	77	73	3.8	46	0	6	11	22	5.7		
STIRLING:																
Stirling	151	36	87	83	79	77	72	3.3	43	6	14	19	26	5.0		
ZETLAND:																
Baltesound	78	43	77	71	67	64	60	4.2	45	13	17	21	29	3.9		
Lerwick	269	49	76	69	66	62	58	3.5	60	16	20	24	30	3.4		

* 'Seldom' = 20 per cent of occasions or 1 year in 5; the figures given are the upper and lower quintiles.

† Root mean square of the variation from the median.

centred at Woburn and having a radius of about 75 miles; the area extends, for example, to Gloucester, Nottingham, Lincoln, Norwich, Tunbridge Wells and Southampton. The isotherm for 80°F excludes the coasts of England (except the strip between Rhyl and Carlisle), the Pennines, the Welsh Mountains, and most of Devon and Cornwall. In Scotland all reporting stations, except those in the extreme north, lie within the 76–80°F range.

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NOTES AND NEWS

551.5(091):551.508.41

An account of some old barometers

During the course of recent months seven Meteorological Office barometers of unusual age have come to light at stations where they have been in regular use until recently. Of these barometers, four were of the 'Fishery' type, loaned to harbourmasters or other local authorities as a safeguard to fishermen before the days of radio forecasts. As the old Meteorological Office stores ledgers are still in existence for virtually all instruments issued from 1855 to 1911, the detailed history of these old barometers can be traced.

The oldest of the group is Fishery Barometer No. 19. This was first issued to a Captain Walker, R.N., at Cawsand Bay, on 12 August 1858, where it remained until at least 1911. In 1920 it was issued to Ullapool, in Ross and Cromarty, where it remains awaiting collection.

Of almost equal age, Fishery Barometer No. M.O. 60 was supplied to St. Helens (presumably Isle of Wight) in 1862. It was transferred to the coastguard, Ryde, in 1875 and to the Harbour Officer, Newlyn, in 1921, from whom it has now been returned. This barometer also bears the mark "No. 285," this presumably being the manufacturer's serial number. It is in excellent condition apart from a broken vernier scale which can be easily repaired.

Just failing to achieve its 'century,' Fishery Barometer No. 99 was first issued to the Town Clerk, Tynemouth, in October 1866, for use at North Shields, where it remained until July 1964. Apart from a broken attached thermometer it is still in good condition.

Relatively a newcomer, Fishery Barometer No. 244 has come to light at Badachro, near Gairloch, Ross and Cromarty. This was issued to the station in June, 1897, where it has remained ever since, apart from a short period when it was returned for repair.

Barometers in regular use for synoptic observations do not as a rule share the longevity of the fishery barometers, largely owing to the risks during their more frequent transfer from station to station. However two very similar station barometers have recently been returned, No. M.O. 1523 from the coastguard synoptic station at St. Mary, Isles of Scilly, and No. M.O. 1525 from the Meteorological Office, Leuchars, Fife. Both are barometers made by Calderara, with iron cisterns, and calibrated at Kew in 1920. The former was issued to St. Mary in 1929, its former history not being known, while the latter reached Leuchars in 1934 after some years in the Science Museum, South Kensington.

Even more unusual, in view of the hazards of life at sea, an old marine barometer made by 'H. Negretti and Zambra' was returned in May 1964 after 44 years of service. This barometer bears the marking of an upright arrow and the figures '99' and is presumably one obtained under War Office contracts placed during or immediately after, the First World War. It also was certified at Kew in 1920 and has been repaired on three occasions, without recertification. The records show that during its life it passed through the hands of the Port Meteorological Officers at Liverpool, London and Southampton, and although no record of all the ships in which it served is available, it was recovered in 1964 from *Capetown Castle*.

The long life of each of these barometers reflects considerable credit upon those responsible for safeguarding and using them. All have been in regular use until recently and in most cases retesting after their return has not disclosed serious defects or errors. At the same time it is not advisable to retain barometers or any other instruments required for accurate measurements for prolonged periods without regular recalibration against a central standard.

A. L. MAIDENS

Decisions of the World Meteorological Organization's Scientific Advisory Committee

The World Meteorological Organization (WMO's) Advisory Committee, the newest committee of WMO consisting of 12 well-known scientists, held its second session in Geneva from 8-12 February 1965. Dr. R. C. Sutcliffe (U.K.) was unanimously elected chairman of the session.

A new feature of the session was the organization of some scientific discussions jointly with the newly-created International Union of Geodesy and Geophysics Committee on Atmospheric Sciences. The meeting of this Committee also took place in the WMO building during the same week. Dr. Blamont (France), Professor Charney (U.S.A.) and Professor Kondratiev (U.S.S.R.) presented papers for these scientific discussions. Professor Sheppard (U.K.) and Dr. Cressman (U.S.A.) also made major contributions.

At one of these discussions, Professor Kondratiev gave an interesting paper on the future possibilities of meteorological satellites including the possible use of meteorologically qualified cosmonauts to obtain observational data. The speaker also discussed the possibilities of establishing a lunar observatory which would have similar characteristics to the planned stationary satellites placed in an equatorial orbit.

Much interest was shown in some important experiments now being developed in the United States and France which would involve the release of a large number of special balloons equipped with suitable instruments and floating with the wind at a number of constant levels. Dr. Blamont, who led the discussions on this subject, explained that the meteorological observations made by these special balloons may be interrogated either by a satellite or by ground stations and the experiments would constitute a feasibility study to find out whether such floating balloons in future could be used as a complement to conventional observations to fill the large gaps over the oceans and in the southern hemisphere. The results of such experiments will play an important role for the planning of the future World Weather Watch.

Many millions of observations have been collected by merchant ships over the last 80 years or so. Among these are measurements of sea surface temperature which now assume new significance to many scientists working on long-term changes in weather and climate. The Advisory Committee agreed that a special effort is necessary to analyse and publish all these long records of data and recommended that WMO should engage a short-term consultant to study this matter.

The Advisory Committee paid considerable attention to questions of meteorological training and in view of the rapidly developing WMO activities in this field, it recommended that the WMO Executive Committee should create a panel of experts to act as a focal point for these activities and to deal with all aspects of scientific and technical meteorological training.

The question of establishing and supporting international research institutes aroused great interest. The Committee was not at the present time in favour of creating one single World Institute under the auspices of WMO but preferred other means of giving support to the various types of such institutes. A new feature of such support was a proposal that WMO should sponsor a WMO international visiting programme. Under this programme, if approved, qualified scientists may be appointed as WMO Visiting Fellows, and assisted to make extended visits for research or educational purposes at participating Research Institutes.

The recommendations of the Advisory Committee will be considered by the WMO Executive Committee at its seventeenth session which will open in Geneva on 27 May 1965. The third session of the Advisory Committee will be held in spring 1966.

METEOROLOGICAL OFFICE DISCUSSION

Operational numerical forecasting

At the Meteorological Office discussion held on 21 December 1964 at the Royal Society of Arts, the opening speaker was Mr. P. Graystone. His topic was the introduction of numerical forecasts in the Meteorological Office on a routine basis, which is intended to follow the installation of the new KDF 9 computer COMET.

Mr. Graystone spoke of the three stages in the production of a computed chart—data extraction, analysis and numerical forecast. Each of these posed new problems in view of the proposed expansion of the forecast area—the latter is intended to cover four times the area of earlier numerical forecasts made with the previous computer METEOR. The larger area should reduce the influence of boundary errors over the essential parts of the chart and permit some extension of the forecast period. The prediction model has been well tested on the previous machine; it has yielded good forecasts at 500 and 200 mb, and the surface forecasts have given useful guidance. The operational system envisages a twice-daily forecast, based on 0000 and 1200 GMT data, with later versions supplemented by 0600 and 1800 reports. It is hoped that the continuity of the new system will lead to an improvement in the computed analyses, which will be reflected in forecasts of greater accuracy.

The discussion was concerned to a large extent with the adaptation of these forecasts for operational use. The computed forecasts are not intended to handle small-scale features, and the detail will need to be inserted; the jet stream in particular is a feature which may cause some difficulty. Another drawback pointed out is that a computed chart carries no degree of confidence, and the forecaster may have a difficult decision when it differs substantially from his own expected development.

The Director-General considered that the introduction of numerical forecasts was the most important advance in meteorology since the Norwegian frontal model. Automation brought problems wherever it was introduced, but in meteorology the experience and judgement of forecasters would still be required.

REVIEWS

A colour guide to clouds by R. Scorer and H. Wexler. $7\frac{3}{4}$ in \times 5 in, pp. vi + 66, illus., Pergamon Press Ltd., Headington Hill Hall, Oxford, 1964. Price: 12s. 6d.

As its name implies the book is intended as a guide to the study of clouds, not only their identification but the processes which cause their formation. In addition to a brief introduction to cloud names and their derivation, there are 11 diagrams with explanatory text to illustrate the physical processes involved in cloud building. The reader is then presented with 48 coloured cloud photographs, two to a page, with notes on the opposite page explaining the processes which cause the cloud formation and drawing attention to any point of special significance. In one or two cases the authors have not expressed themselves clearly (plates 16 and 18). The last two pictures, taken from a Mercury satellite, bring the book right up to date. Finally there is a four-page section on practical studies, with helpful advice on the determination of cloud height, speed of movement, growth and development, and brief tips on cloud sketching and photography.

The authors intend the book to be carried to the office, workshop or school and on all trips so that the clouds can be studied at all times and the book size and the excellent index have been well designed for this purpose.

The authors are well known and respected in meteorological circles. Professor Scorer has long campaigned for the identification of cloud forms by virtue of their formation rather than by their Latin names as used by meteorologists for coding and reporting purposes and this book presents his ideas to the amateur. It will appeal to the physicist, naturalist, geographer, artist and layman with only an amateur interest in the sky. Little knowledge of physics is required to understand and use the book. Schoolboys interested in the weather will find it both useful and instructive.

Some of the coloured photographs are reproduced from colour slides and, as is usual, have suffered in the reproduction process but, for its price, the book is excellent value for money.

It is rather surprising that one so experienced as Professor Scorer should wrongly define cumulonimbus in Plate 13 and thus misname both Plates 10 and 11. In international meteorological terminology cumulonimbus clouds are only so named after their tops have lost their turreted form and become fibrous showing that glaciation has occurred.

R. K. PILSBURY

The English climate by H. H. Lamb. 7 $\frac{3}{4}$ in \times 5 in, pp. xi + 212, *illus.*, English University Press, 102 Newgate Street, London E.C.1, 1964. Price: 12s. 6d.

Ten years after the first edition of this book by the late Dr. C. E. P. Brooks, a much modified version has been prepared by Mr. H. H. Lamb. As the Foreword says, the author "has considered our weather as part of a whole, that of the Northern Hemisphere." The book is intended for all interested in weather, professionally or otherwise, and care is taken to familiarize the non-professional with the recently adopted Celsius scale of temperature, etc.

Chapters 2-4 contain much new material and reflect the rapid developments in synoptic and dynamical climatology. Chapter 2 outlines the general circulation of the atmosphere and the role of the oceans. Heat and momentum transport are mentioned, but there is surprisingly no reference to moisture flux and its climatological significance. Chapter 3 deals with atmospheric perturbations and their associated weather patterns. The approach via tracers of wind motion, tropospheric and stratospheric flow, and the jet stream and polar front is particularly interesting. This is followed in Chapter 4 by an examination of winds, warmth and weather types. The characteristics of air masses over Britain and the author's classification of weather types are summarized, although this section would be strengthened by a closer interrelation of these two concepts and by illustrations of synoptic situations.

The major lines of Chapters 5-9, which are more specifically concerned with Britain's climatic characteristics, are unchanged from the first edition, but there are several new maps, and added material dealing, for example, with cloud processes and the incidence of driving rain. The discussion of orographic rainfall as a distinct type (pp. 65-66) requires amendment. Our lack of progress in bioclimatology, compared with dynamical climatology is evident in Chapter 8—Climate and health. Nevertheless, Huntington's views on climate and civilisation could occupy a less prominent place. Adherence to the layout of the first edition in these five chapters rather detracts from the author's attempt to examine our climate in modern synoptic terms.

Chapter 10—Seasons and Saint's days—returns to the theme of synoptic climatology and might more appropriately follow Chapter 4 in a future edition. The chapter provides an intensive summary of recent studies of natural seasons, spells and singularities, particularly Mr. Lamb's own notable contributions, and it is supplemented by a useful calendar of singularities in Appendix I. The student of the general circulation will find much of interest in the outline of hemispheric circulation processes and their physical bases. However, it seems strange that the opportunity to outline the methods employed in long-range forecasting was not taken. Chapter 11 deals briefly with post-glacial and historic changes of climate and is also supplemented by a calendar of historic weather events since 1500 (Appendix II). The final chapter on weather maps could be incorporated with Chapter 3 or placed as an Appendix.

Only a few misprints were noted: the heading of Table 4, and 'High' and 'Low' omitted on Figure 1. The suggested comparison (p. 9) of Figures 1 and 2 is made inconvenient by setting one horizontally and the other vertically and numbering of all tables would simplify references to them. Standard deviation (p. 98) is not defined and significance levels (p. 144) require fuller explanation.

The layout of the new edition benefits greatly from the use of sub-headings and the indexing is improved.

Numerous up-to-date references will make the book especially valuable to students. The author's style is eminently readable and the book provides a welcome addition to the literature on our climate at a very moderate price.

R. G. BARRY

LETTER TO THE EDITOR

551.571.2(412):551.571.36

A new record of low humidity

The article on low humidities in 1964* was completed just before the occurrence of the longest spell of very low humidities yet recorded at the Cairngorm high-level climatological stations. This spell, which lasted from 8 to 11 November may well be the longest ever autographically recorded in the British Isles.

The steep drop in relative humidity, as recorded by the hair hygrograph, began at both stations between 1500 and 1600 GMT on 8 November, and the final steep rise about 1000 GMT on 11 November. During this period of over 66 hours, there was only one break of 8 hours (from about 2000 GMT on 9th to about 0400 GMT on 10th) during which the relative humidity ceased to be remarkably low. For 33 hours the relative humidity as recorded on the Cairngorm hair hygrograph was below 20 per cent and at the Coire Cas Shielling also it remained below 20 per cent nearly as long as this. The lowest levels were reached during the afternoon of 10 November, when it was 10 per cent or below for about 12 hours at the upper station and for about 4 hours at the lower station. The very lowest value of about 8 per cent at each station, occurred about 2000 GMT on that day.

The nearby station at Achnagoichan showed values not very different from usual except for a steep drop on 10 November, about 0700 GMT, followed by a gradual rise; the lowest value recorded was about 31 per cent at 0900 GMT. In the *Daily Weather Report* the only occurrence noted of an unusually low relative humidity was at 0000 GMT on 11 November, when it was 23 per cent at Cape Wrath.

Inspection of the wet-bulb and dry-bulb temperature observations made four times a day (0300, 0900, 1500 and 2100 GMT) at the two high-level stations, Lowther Hill (2377 ft) and Great Dun Fell (2780 ft) did however reveal that exceptionally low relative humidities occurred there. At the former the lowest reading was 18 per cent at 1500 GMT on 10th, while at the latter it was 7 per cent at both 2100 GMT on 9th and 0900 on 10th. The 0900 GMT observations at Moor House (1825 ft), near Great Dun Fell, did not indicate a relative humidity below 60 per cent.

The surface synoptic situation on 8 November was of a high extending from the Black Sea to Denmark. This slowly retreated eastwards, while a deep depression over the Atlantic began to dominate the situation during 11 November. The *Daily Aerological Records* show a pronounced high centred over England on the 500 mb contour chart for 8 November; this had moved slightly eastward on the 9th and 10th, but was beginning to disappear on 11th. The upper air soundings reveal an unusually thick layer of strikingly dry air extending from

*GREEN, F. H. W.; The incidence of low relative humidity in the British Isles. *Met. Mag., London*, 94, 1965, p. 81.

the tropopause down to below the 800 mb level. The lowest relative humidity noticed was 7 per cent at the 703 mb level during the 2330 GMT sounding from Aughton on 9 November, but relative humidities of 25 per cent or below were quite common down to at least 850 mb level, which is not so very much higher than Cairngorm. So it looks as though this dry, subsiding air reached the surface at a few places, such as Cairngorm, Lowther Hill and Great Dun Fell. There are however no other recording stations than these above 2000 ft, so it could well be that very low humidities occurred on many other hills where no instruments are maintained.

*The Nature Conservancy, Speyside Research Station,
Aviemore, Inverness-shire*

F. H. W. GREEN

OFFICIAL PUBLICATION

The following publication has recently been issued:

GEOPHYSICAL MEMOIRS

No. 109—*Mean streamlines and isotachs at standard pressure levels over the Indian and west Pacific Oceans and adjacent land areas*, by R. Frost, B.Sc. and P. M. Stephenson, M.Sc.

This Memoir consists primarily of charts of the mean wind flow at 700 mb, 500 mb, 300 mb and 200 mb for the mid-season months of January, April, July and October, based on the latest available rawind data supplemented by pilot-balloon and aircraft observations.

The main features of the flow patterns are discussed and a simple explanation is offered of certain features which have no parallel elsewhere in the tropics.

The Memoir will be of considerable value to aviation planners and to climatologists as well as to forecasters in the region who will find in the charts a useful basis for daily analysis and prognosis.

PUBLICATION RECEIVED

Atlas of planetary solar climate Vol. IV by Clyde J. Bollinger. 12 in × 8½ in, pp. 44, illus., Bollinger Climatic Research Service, Norman, Oklahoma, U.S.A., 1964.

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AN EXAMPLE OF VENTILATION ERROR IN THE DRY-BULB AND WET-BULB PSYCHROMETER

By R. F. ZOBEL, O.B.E.

Introduction.—Vapour pressure in the atmosphere is determined from an equation of the form

$$e_w - e = Ap (T - T_w) \quad \dots (1)$$

where e_w is the saturation vapour pressure at the wet-bulb temperature T_w , e is the vapour pressure, T is the dry-bulb temperature, p is atmospheric pressure (usually taken as constant at 1000 mb for use at the surface) and A is a constant which takes values that vary with the rate of ventilation of the wet bulb.

Meteorological Office hygrometric tables¹ use a value of $A = 7.99 \times 10^{-4}$ where T is in °C and exceeds 0°C and pressures are in millibars, for use with readings taken in a standard thermometer screen where the rate of passage of air past the wet bulb is assumed to be 1–1.5 metres per second. Humidity slide-rules used in the Office are based on the same conventions. It is specifically stated in the introduction to the tables that they (and consequently, the slide-rule) are not suitable for a psychrometer exposed in stagnant air. But there is no other recourse open to the observer if the air is, in fact, stagnant. It is the purpose of this note to draw attention, by reference to a specific example, to the rather large errors that occasionally occur due to this 'misuse' of the tables or slide-rule.

Occasions liable to produce errors.—The relative humidity U is given by

$$U = 100e/e_T \quad \dots (2)$$

where e_T is the saturation vapour pressure at the dry-bulb temperature.

Combination of equations (1) and (2) leads to

$$U = 100 \frac{[e_w - Ap (T - T_w)]}{e_T} \quad \dots (3)$$

The constant A is only appropriate to a ventilation rate of 1–1.5 m/s (2–3 knots). For a different wind speed the constant may be written $A + \Delta A$ and in particular, if the air is stagnant, $A + \Delta A_0$. In stagnant air there will be a

different wet-bulb temperature (T_w') and saturation vapour pressure at T_w' (e_w'), and equation (3) becomes

$$U = 100 \frac{[e_w' - p(A + \Delta A_0)(T - T_w')]}{e_T} \dots (4)$$

Use of the tables however leads to a value

$$U' = 100 \frac{[e_w' - Ap(T - T_w')]}{e_T} \dots (5)$$

and the error in relative humidity is given by

$$\varepsilon_U = U' - U = 100 \frac{p \Delta A_0 (T - T_w')}{e_T} \dots (6)$$

The error is therefore proportional to $(T - T_w')/e_T$. Since e_T decreases as the temperature decreases, the error will be greatest at low humidities and temperatures. In the atmosphere, however, observed values of $(T - T_w')$ decrease as T (or e_T) decreases, but the insertion of a few probable values shows that the higher values of $(T - T_w')/e_T$ will occur at low temperatures. At sub-freezing temperatures the values of A and ΔA_0 are changed but it is probable that the largest errors may occur in dry, stagnant air in cold climates.

Such conditions are seldom or never experienced in the British Isles. The situations which produce the lowest humidities are warm days in June and July and the occurrence of continental air in April.² Although the latter may well produce the larger errors because of the lower temperature level, the example given below belongs to the former. It was brought to light because measurements from a low-flying aircraft produced dew-points which were not reconcilable with those obtained from the dry-bulb and wet-bulb psychrometer on the ground.

The physical reason for the error is that evaporation from the wet-bulb muslin produces a layer of humid air around the bulb. This is normally removed by the flow of air past the bulb. In the absence of such a flow, the moist air is removed by the slower process of diffusion, and evaporation at the wet bulb is less rapid. Consequently the wet-bulb depression is reduced.

An example.—The weather on 8 July 1959 was very hot, dry and windless over southern England, as indicated by the weather map for 1200 GMT (Figure 1).

The dew-points (after conversion from °F) recorded at Farnborough during the day are shown in Table I. Reported winds are also given.

TABLE I—HUMIDITIES AND WINDS AT FARNBOROUGH ON 8 JULY 1959

Time (GMT)	09	10	11	12	13	14	15	16	17	18
Dew-point (°C)	14.9	14.8	15.5	13.9	15.3	10.9	13.8	12.9	12.6	14.4
Wind speed (kt)	00	00	00	03	02	07	03	01	04	05

At 1400 GMT the wind was the highest and the dew-point the lowest reported during the day. This dew-point is anomalous but in fact it is the most likely to be correct because the wind was strong enough to give the ventilation rate assumed in the official tables.

Discussion.—The hair hygograph is not subject to ventilation errors in the same way as the wet-bulb thermometer because there is no water mass associated

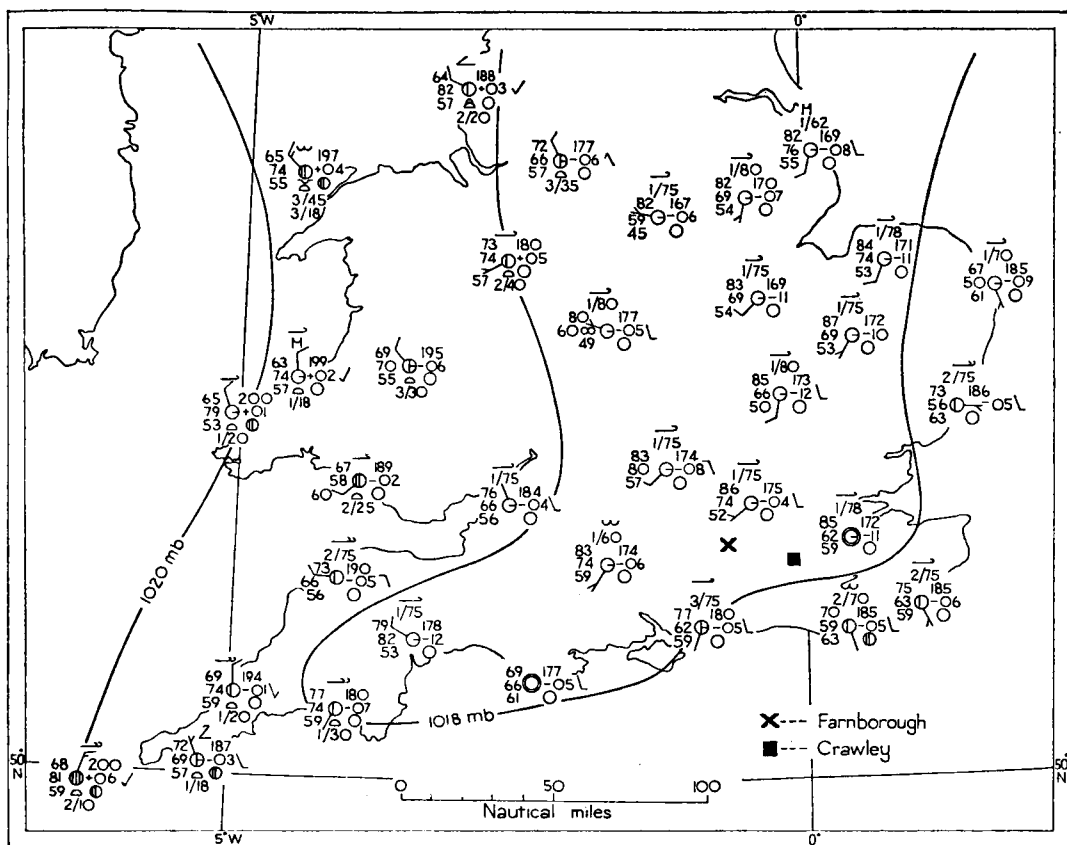


FIGURE 1—WEATHER MAP FOR SOUTHERN ENGLAND, 1200 GMT, 8 JULY 1959

with the hair. It is not, however, a highly accurate instrument and the *Handbook of meteorological instruments*³ indicates this by saying that “errors at any point of the scale above 20–30 per cent do not normally exceed about ± 5 per cent, but the sensitivity is about ± 1 to 2 per cent.” Nevertheless it will serve as a useful working standard for relative humidity U . It is possible, for this particular occasion, to estimate the likely errors of the hygrograph and so to arrive at corrected values of the errors due to lack of ventilation of the wet bulb.

Table II shows the dry-bulb temperatures for each hour corresponding to those on the hygrogram for 8–9 July 1959. The whole period of 24 hours has been considered since the winds were very light and there was a large range of humidity values. The humidities on the uncorrected hygrogram and the humidities derived by slide-rule from the dry-bulb and wet-bulb temperatures are given in columns (3) and (4) respectively, and the apparent error ϵ_U is given in column (5).

It will be seen that at 1400 GMT there was an apparent error of 5 in the percentage humidity which corresponds to an error in dew-point of 2.9°C . At this time the observed wind speed at 10 metres was 7 knots, which may be regarded as providing normal ventilation in the thermometer screen. The recorded humidity by dry and wet bulb can therefore be taken as correct and the hygrograph reading is thus 5 too low.

TABLE II—HUMIDITY ERROR IN RELATION TO WIND, TEMPERATURE AND HUMIDITY,
8/9 JULY 1959

Time	Dry-bulb temperature	Apparent U by hygrograph	Recorded U by dry and wet bulbs	Apparent ξU (4) - (3)	ξU corrected for hygrograph error	Dew- point error	$T - T_w'$ $\frac{eT}{eT}$	Wind speed
GMT (1)	°C (2)	per cent (3)	(4)	(5)	per cent (6)	°C (7)	(°C/mb) (8)	knots (9)
8 July								
09	24.9	42	54	12	9	2.8	0.19	00
10	26.7	38	48	10	6	2.1	0.21	00
11	28.3	34	46	12	8	2.9	0.18	00
12	29.5	30	38	8	4	1.9	0.23	03
13	30.6	26	39	13	8	3.8	0.22	02
14	31.7	23	28	5	0	0.0	0.26	07
15	31.6	23	34	11	6	3.0	0.23	03
16	31.1	24	33	9	4	1.9	0.24	01
17	30.7	24	33	9	4	2.0	0.25	04
18	29.4	32	40	8	4	1.6	0.22	05
19	27.7	38	46	8	4	1.3	0.21	02
20	26.1	45	54	9	6	1.9	0.18	01
21	24.0	53	62	9	7	2.1	0.16	00
22	22.1	61	65	4	2	0.4	0.16	00
23	20.6	65	67	2	1	0.2	0.15	00
24	19.2	68	74	6	5	1.1	0.13	00
9 July								
01	19.2	69	70	1	0	0.5	0.13	01
02	18.5	73	79	6	5	0.9	0.10	00
03	16.8	80	83	3	3	0.6	0.09	00
04	16.5	84	82	-2	-2	-0.4	0.09	00
05	15.8	84	84	0	0	0.0	0.09	00
06	16.2	82	83	1	1	0.1	0.09	00
07	17.4	76	78	2	2	0.5	0.11	02
08	19.2	70	71	1	0	0.0	0.14	02

The hygrograph error at the higher humidities was estimated on the following basis. Certain editions of Kaye and Laby⁴ give $A = 0.001$ for a small closed room, i.e. ΔA_0 is about 2×10^{-4} . Insertion of this value in equation (6), along with $(T - T_w')/eT = 0.09$ (column (8) at 0300 GMT of Table II), shows that if the hygrograph was reading accurately at 80 per cent it should have read about 2 per cent below the values deduced from the dry-bulb and wet-bulb thermometers. It is clear from column (5) of Table II that this was closely the case. It has therefore been taken that the hygrograph was subject to errors of 5 per cent and 0 per cent at readings of 25 and 80 per cent respectively and that the relationship was linear. Column (6) of Table II shows values of ξU , which are those in column (5), corrected on the basis indicated above. For the benefit of synoptic meteorologists the corresponding errors in dew-point are shown in column (7).

It is now possible, from equation (6), to obtain an average value for ΔA by plotting $(T - T_w')/eT$ against ξU as corrected. This should give a straight line through the origin, the slope being proportional to ΔA . This has been done in Figure 2 where the digits above the crosses denote wind speed and those beneath, in brackets, show the time. There is a good deal of scatter as is to be expected from the adoption of the hygrograph as a standard and from the fact that the wind was not always calm, but a straight line has been drawn by eye through the origin. This gives a value of $\Delta A = 2.4 \times 10^{-4}$, so giving a value of $A = 10.4 \times 10^{-4}$. This value was obtained for very low wind speeds at 10 metres; on only 5 of these 24 occasions did the wind exceed 2 knots (mean speed over 24 hours = 1.4 knots or 0.7 m/s).

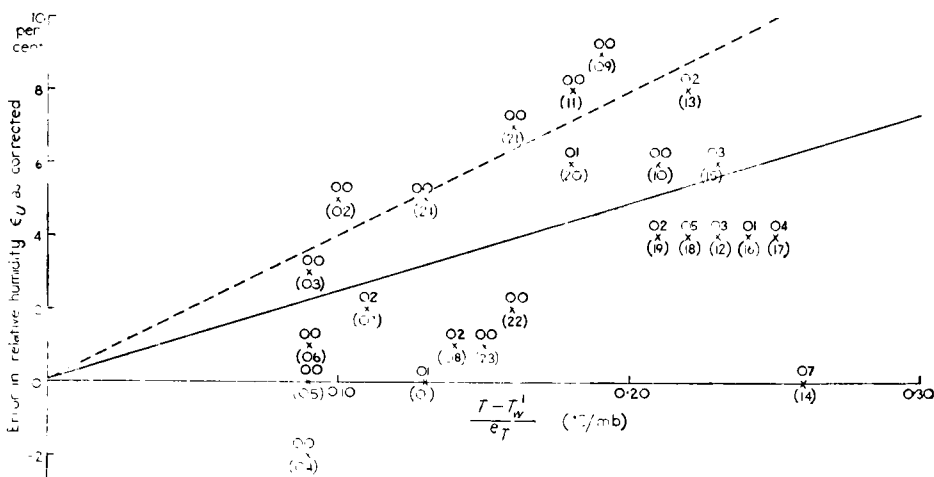


FIGURE 2—RELATIONSHIP BETWEEN THE CORRECTED ERROR IN RELATIVE HUMIDITY, $(T - T_w')/eT$ AND WIND SPEED

The straight line corresponds to $A = 10.4 \times 10^{-4}$, the dotted line to the Austrian value of A . Digits above the crosses denote wind speed (knots), those below (in brackets) the time (GMT), see Table II.

The Kaye and Laby value of A for a small closed room can also be deduced from a paper by Powell⁵, though it is possible that the Powell, and Kaye and Laby figures are based on the same observations. Another value, 12.01×10^{-4} , can be deduced from Austrian figures quoted by Penman⁶ for winds of 0–0.5 m/s. The humidity errors in column (6) of Table II may therefore be regarded as serving as a reliable example of the errors which may occur as a result of inadequate wet-bulb ventilation.

Closer examination of Figure 2 shows the sensitivity of A to wind speed. It confirms that some of the scatter is due to finite wind speeds, since values of ξ_U corresponding to the higher wind speeds tend to fall below the line, whilst above the line there are only values corresponding to the lower wind speeds. The dotted line corresponds to the Austrian value of A . It passes amongst points all of which are associated with very light winds. The Austrian value is therefore supported by the present observations as being appropriate to very stagnant conditions.

Forecasting implications.—Occasions when errors may occur in the dry-bulb and wet-bulb psychrometer are not difficult to recognize at the time. When estimating nocturnal cooling rate, or the possibility of fog formation on such occasions, forecasters may find it useful to compare surface dew-points as derived from dry bulbs and wet bulbs and from the hygrogram. The latter should be preferred if they are appreciably lower, so long as there is adequate confidence in the accuracy of the hygrograph. This means that checks, particularly at low humidities in non-stagnant air, should be made whenever possible between the two instruments. It should also be remembered that the zero of a hygrograph cannot be set accurately by reference to the dry-bulb and wet-bulb psychrometer if the wind is very light unless the relative humidity is close to 100 per cent.

Conclusions.—There are occasions, rather infrequent in the British Isles, when relative humidities and dew-points derived from dry-bulb and wet-bulb thermometers may be in error. In the data examined the error was as much as 9 per cent for humidity and 3.8°C for dew-point.

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551.582(548):612.59

AN INDEX OF COMFORT FOR GAN

By C. N. McLEOD

Introduction.—A recent paper by Stephenson¹ examined the climate of Singapore from the point of view of human comfort using the 'effective temperature' scale devised by the American Society of Heating and Ventilating Engineers² and published by the Air Ministry.³ As the results proved of considerable interest, particularly to persons stationed in or about to be posted to the Far East, it was thought worthwhile to extend the investigation to other stations in the area and this article describes the annual and diurnal variation of effective temperature at Gan. Comparison of these results with those for Singapore is of interest as, although both islands are close to the equator, Gan is near the centre of the Indian Ocean and therefore divorced from any continental effects which might influence Singapore's climate.

Summary of data used.—Climatological data for Gan for the period January 1959 to July 1964 were used to calculate the mean dry-bulb and wet-bulb temperatures and from these the mean relative humidity for each month of the year (Table I) together with mean scalar wind speeds (Figure 1).

TABLE I—MEAN DRY-AND WET-BULB TEMPERATURE AND RELATIVE HUMIDITY FOR GAN FOR JANUARY 1959 TO JULY 1964

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean dry-bulb temperature (°F)	81.8	82.1	83.0	82.7	82.7	82.0	81.4	81.3	81.7	81.1	81.1	81.1
Mean wet-bulb temperature (°F)	76.8	76.9	77.3	77.7	77.9	76.8	76.7	76.7	76.8	76.6	76.5	76.6
Mean relative humidity (per cent)	79	78	76	79	80	78	80	81	79	81	80	81

The corresponding mean 24-hour effective temperature, as read from the nomogram in A.P. 1269B for lightly-clad persons, together with the dry-bulb and wet-bulb values are plotted in Figure 2.

Three-hourly values of dry-bulb and wet-bulb temperatures and wind speed were then calculated for the same period, to determine the diurnal variation of the effective temperature. The variations over 24 hours for each

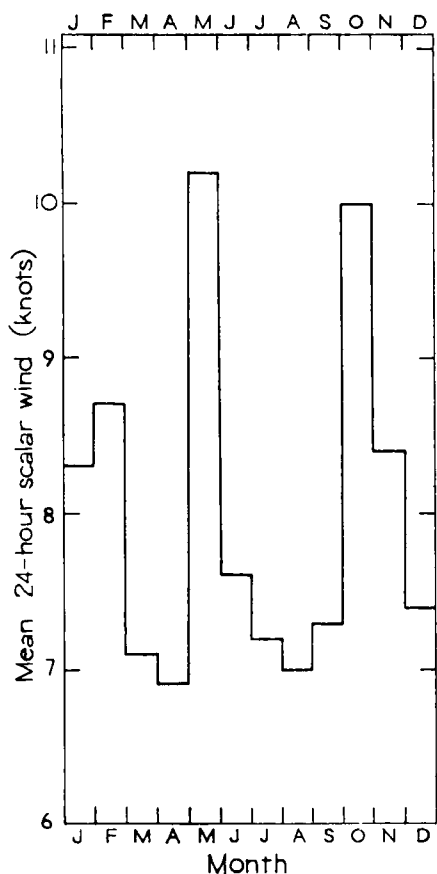


FIGURE 1—MEAN 24-HOUR SCALAR WIND AT GAN

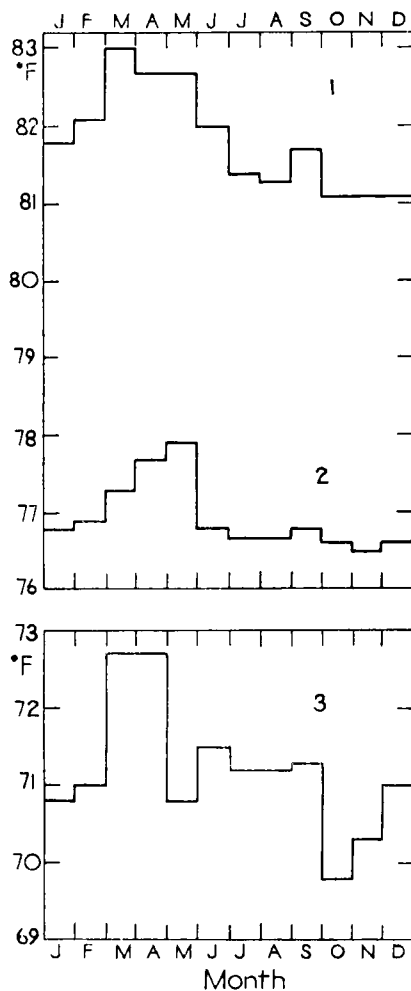


FIGURE 2—MEAN 24-HOUR TEMPERATURES AT GAN

1. Dry-bulb temperature; 2. Wet-bulb temperature; 3. Effective temperature.

Both figures are for the period January–July 1959–64 and August–December 1959–63.

of the months January, April, July and October are shown in Figure 3, whilst Figures 4 and 5 show the effective temperatures which would correspond to various wind speeds at 0500 and 1400 zone time in April (one of the hottest months) assuming that dry-bulb and wet-bulb temperatures were fixed at the appropriate average values for each of these hours.

Discussion of data.—

1. *Annual variation of effective temperature.*—Figure 2 shows that there is only a small variation in the mean effective temperature throughout the year, but the main feature is that every month falls within the optimum range for hot climates, viz. 69 to 73°F.

The figures do suggest that October and November are the most comfortable and March and April the least comfortable months, although this might not be appreciated by the individual in view of the small range of effective temperature (2.9°F). The remaining months exhibit a very small variation in effective temperature (0.7°F), suggesting that they are very much alike. It is a little

unexpected to find that maximum values do not occur during the months immediately following both the equinoxes, when the sun is virtually overhead, but the stronger winds in May and October more than offset the increased effect of the sun's radiation. The result that there is little to choose between the months accords well with experience.

Table I confirms Stephenson's conclusion that relative humidity alone is not a reliable guide to comfort, since the most comfortable months in Gan are those with the highest relative humidity and one of the least comfortable months has the lowest value.

2. *Diurnal variation of effective temperature.*—Figure 3 shows that there is a marked diurnal variation of effective temperature, with the maximum in the early afternoon and the minimum around 0500 zone time. In April and July there is a suspicion of a secondary maximum around 2300 zone time but this is absent in January and October.

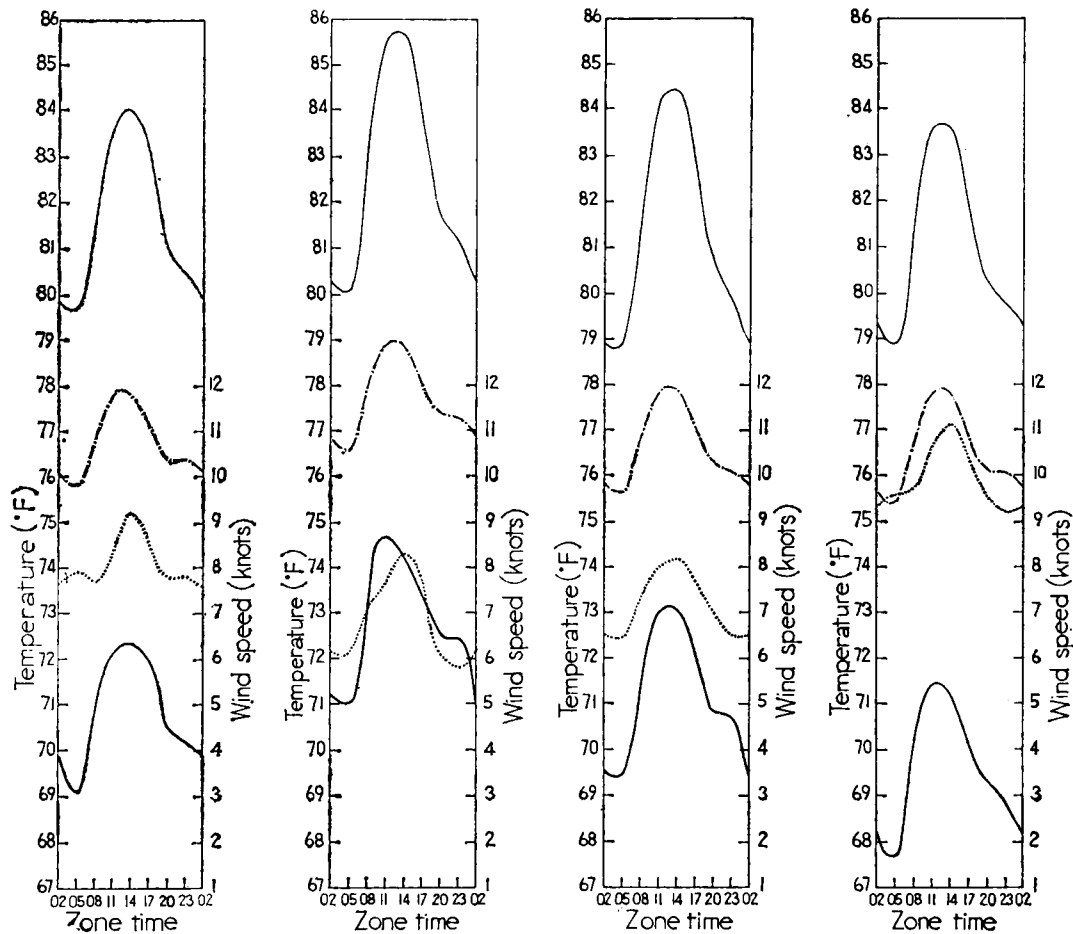


FIGURE 3—DIURNAL VARIATION OF WIND SPEED AND TEMPERATURE AT GAN
 ——— Dry-bulb temperature - - - - Wet-bulb temperature
 Wind speed ——— Effective temperature
 From left to right the diagrams are for January, April, July, and October.

Other points of interest arising from the diagrams of diurnal variation are:

- (i) The time of maximum discomfort is usually an hour or so earlier than the time of maximum temperature.

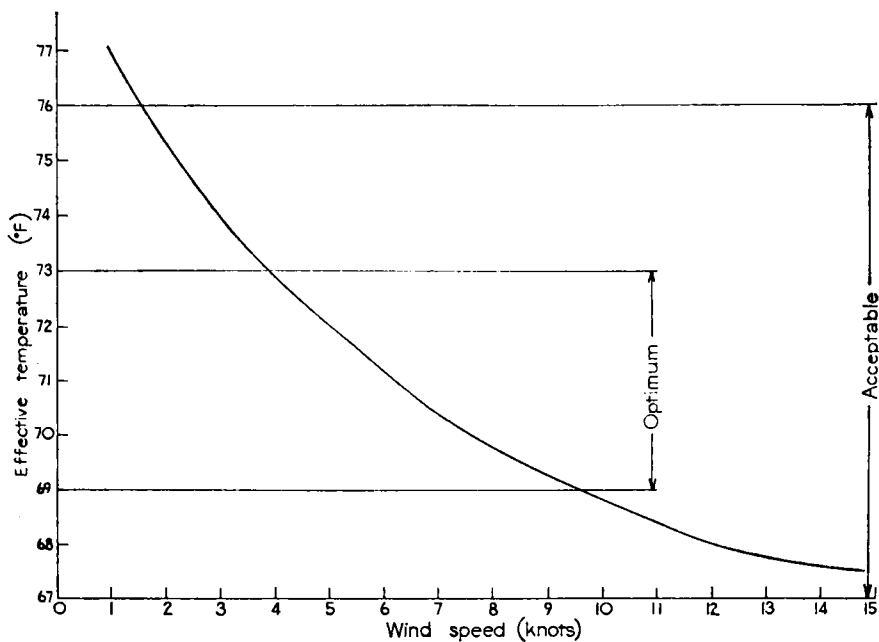


FIGURE 4—VARIATION OF EFFECTIVE TEMPERATURE WITH WIND SPEED AT GAN AT 0500 ZONE TIME FOR AN AVERAGE APRIL

Average dry-bulb temperature 80.1°F
 Average wet-bulb temperature 76.6°F

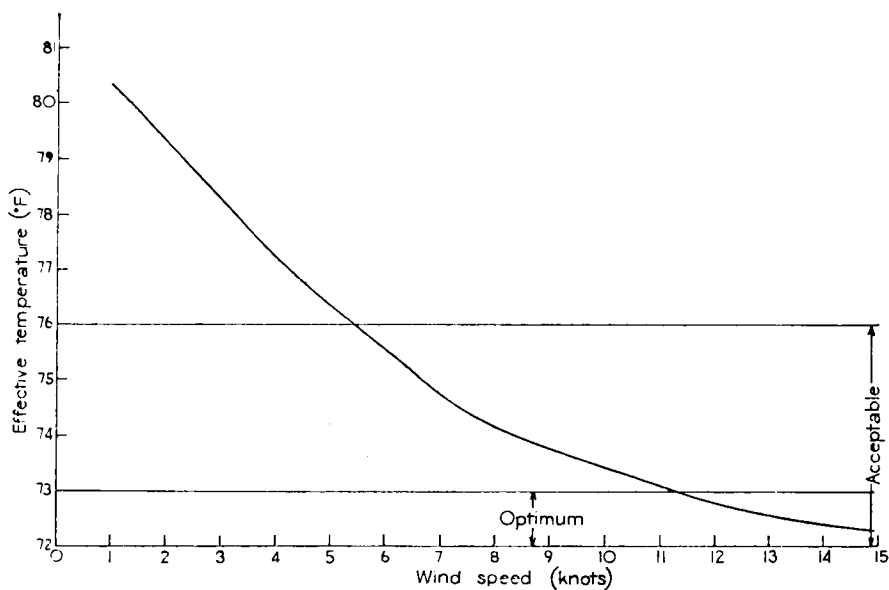


FIGURE 5—VARIATION OF EFFECTIVE TEMPERATURE WITH WIND SPEED AT GAN AT 1400 ZONE TIME FOR AN AVERAGE APRIL

Average dry-bulb temperature 85.7°F
 Average wet-bulb temperature 78.9°F

- (ii) The diurnal variation of the effective temperatures is not as great as that of the corresponding dry-bulb temperatures, whilst the annual variation of the former is greater than that of the latter.
- (iii) Taking 69°F to 73°F effective temperature as the optimum comfort zone for the tropics, then:
 - (a) January and October are not at any time of the day too hot and during the early hours in October the effective temperature is too low for comfort.
 - (b) April is uncomfortably hot between 0800 and 1800 zone time and Figure 5 shows that on an April afternoon a wind speed of between 11 and 12 knots would be required to produce optimum comfort.
 - (c) July is uncomfortably hot between 1100 and 1400 zone time.

3. *Effect of rainfall and sunshine.*—During most periods of rain at Gan the wind is strong and squally, which combined with a temperature in the low seventies reduces the effective temperature at times to below 60°F making conditions uncomfortably cool indoors and most unpleasant outdoors. The monthly rainfall averages suggest that these conditions are most likely to occur during the period October to January and in May and June (Table II).

Gan enjoys a fair proportion of sunshine, about two-thirds of the daylight hours being sunny. Europeans, therefore, tan very easily and quickly and some form of protection against sunshine is necessary, particularly on first arrival at the island.

TABLE II—MEAN RAINFALL AND SUNSHINE AT GAN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (inches)	10.0	5.1	4.2	7.2	9.6	8.2	6.5	7.1	6.6	11.1	8.2	11.3
Oct. 1957–July 1964												
Sunshine (hours)	231	205	270	243	218	230	216	220	223	209	238	234
June 1960–July 1964												

Comparison with Singapore.—Table III compares the mean monthly values of effective temperature at Singapore and Gan.

TABLE III—MEAN EFFECTIVE TEMPERATURES AT SINGAPORE AND GAN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Singapore	71.1	72.6	74.6	76.1	76.9	75.9	74.9	74.6	74.9	75.0	73.9	72.6
Gan	70.8	71.0	72.7	72.7	70.8	71.5	71.2	71.2	71.3	69.8	70.3	71.0

Inspection of this Table and of the diurnal variation, rainfall and sunshine values for the two stations reveals the following:

- (i) In every month of the year Gan is more comfortable than Singapore and does not experience the latter's pronounced peaks of discomfort in May and October.
- (ii) From December to February Gan and Singapore experience some of their heaviest rainfall and have very similar effective temperatures.
- (iii) The diurnal variation of effective temperature is much the same at both stations, although Gan barely shows the secondary maximum found at Singapore around midnight.
- (iv) Gan enjoys more sunshine than Singapore and European residents appear to tan more readily there than in Singapore.

Conclusions.—

(i) For assessing climatic comfort in the tropics the effective temperature is undoubtedly a good index, the results obtained being in accord with experience both in Gan and Singapore, whilst relative humidity values alone are misleading.

(ii) Forced ventilation by means of fans is just adequate for producing optimum comfort during the more extreme heat conditions in April whilst during rainy periods some form of protection against excessive ventilation is desirable.

(iii) Experience confirms that Gan enjoys a more comfortable climate than one would normally expect at a place near sea level in the tropics, a conclusion which is further supported by the Senior Medical Officer's statement that prickly heat is rare at Gan except amongst people whose work takes them into artificially heated areas (kitchens, power houses, etc.).

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NOTE ON THE ERRORS INVOLVED IN COMPUTING MEAN COMFORT INDICES FROM MEAN VALUES OF DRY-BULB AND WET-BULB TEMPERATURES AND WIND SPEED

By P. M. STEPHENSON and C. N. McLEOD

Recent papers by Stephenson¹ and McLeod (preceding article) presented mean values of a comfort index (effective temperature) for Singapore and Gan respectively, computed from mean values of dry-bulb and wet-bulb temperatures and mean wind speeds. The question has been raised whether such computations do give true average comfort indices or whether perhaps a correlation between dry-bulb and/or wet-bulb temperature and wind speed leads to misleading results.

A paper by Webb² based on measurements in Singapore, throws some light on this point. Webb calculated the partial correlation coefficients of the comfort assessment made by his subjects with temperature, vapour pressure and the square root of wind speed, and concluded that there was a "very highly significant correlation in all three cases unaffected by the correlation between temperature and air velocity." This does not completely answer the question however because, as Webb has shown, comfort correlates with the square root of wind speed and $(\Sigma\sqrt{v})/n \neq \sqrt{(\Sigma v)/n}$ unless all the values of v , the wind speed, are equal. In order to evaluate the likely maximum difference between the expressions $(\Sigma\sqrt{v})/n$ and $\sqrt{(\Sigma v)/n}$ for typical Singapore values of wind speed, their values were calculated using 3-hourly observations from Changi for January 1964, January being a month in which a large range of wind speeds is normally found in Singapore. The results were:

$(\Sigma\sqrt{v})/n = 21.5$ (feet/minute)[‡] and $\sqrt{(\Sigma v)/n} = 25.5$ (feet/minute)[‡] the difference being 4.0 (ft/min)[‡]. According to Webb the coefficient of temperature equivalent of \sqrt{v} is -0.231 , so that the likely maximum error in effective temperature from this source is $-4 \times 0.231 = -0.92^\circ\text{F}$.

To take the question a stage further, the difference between an average effective temperature calculated from individual observations and one calculated from average values of temperature and wind speed also depends on the range of values of these elements and the irregularity of their distribution. In Singapore and Gan, temperatures and wind speeds only fall outside a fairly narrow range of values during periods of rain and again during calms. The average percentage of calms at Gan is 11 and at Changi is 20 whilst the average duration of rainfall is about 5 per cent of the time at both stations. Thus only a relatively small proportion of the observations would fall markedly outside the normal rather restricted range of values. The true average effective temperature would, therefore, be unlikely to differ very much from that found using mean temperatures and wind speeds.

In order to verify this conclusion and to assess the actual magnitude of the error, effective temperatures were calculated by the two methods for:

- (i) June 1960 at Changi, when using observations at 0600 and 1800 GMT, the dry-bulb temperature varied from 75.2 to 91.0°F, the wet-bulb from 74.0 to 81.0°F, the wind speed from 0 to 11 knots, and the rainfall was 4.6 inches above the average of 5.5 inches.
- (ii) October 1963 at Gan, when using 3-hourly observations, rain fell for 12.3 per cent of the time and was 4.2 inches above the average of 11.1 inches, and the wind was calm on 7 per cent of occasions.
- (iii) April 1964 at Gan, when using 3-hourly observations, rain fell for 5.8 per cent of the time and was 1.8 inches above the average of 7.2 inches, and the wind was calm on 12 per cent of occasions.

The results, together with frequency tables of effective temperature at Gan, are shown in Tables I and II.

TABLE I—COMPARISON BETWEEN THE TRUE AND COMPUTED AVERAGE EFFECTIVE TEMPERATURE AT CHANGI AND AT GAN

	True average effective temperature	Computed average effective temperature <i>degrees Fahrenheit</i>	Error	Per cent of annual range
Changi June 1960	74.2	73.5	-0.7	12.1
Gan October 1963	69.8	69.5	-0.3	10.3
Gan April 1964	73.7	73.0	-0.7	24.1

It is concluded that mean comfort indices computed from mean dry-bulb and wet-bulb temperatures and mean wind speeds for Singapore and Gan are unlikely to differ by more than 1°F from true mean comfort indices. An error of this magnitude would not materially effect the conclusions reached in the paper on Singapore¹ as it represents only a small proportion of the annual range of effective temperatures and, in any case, the method used for calculating the wet-bulb temperature in that paper could itself lead to errors of up to 1°F, as stated in the text.

In the case of Gan, where the annual range of effective temperature is smaller, the error could be more serious. However, in all four calculations performed above, the error is of the same sign and of approximately the same magnitude so the conclusions reached in the Gan paper, which in any event did not stress the annual variation of effective temperature, are almost certainly still valid.

TABLE II—FREQUENCY OF EFFECTIVE TEMPERATURES AT GAN IN OCTOBER 1963
AND APRIL 1964

Effective temperature <i>degrees Fahrenheit</i>	Frequency	
	October 1963	April 1964
63	15 (≤63°F)	
64	11	
65	11	
66	10	8 (≤66°F)
67	18	7
68	19	7
69	30	10
70	38	15
71	19	21
72	24	25
73	18	26
74	11	24
75	8	20
76	7	21
77	9 (≥77°F)	22
78		12
79		12
80		10 (≥80°F)
	80 per cent of the observations gave values between 65 and 74°F	80 per cent of the observations gave values between 69 and 78°F

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THE YEARLY DISTRIBUTION OF RAINFALL INTENSITIES

By A. L. H. GAMESON and R. D. QUAIFFE
Water Pollution Research Laboratory, Stevenage

Introduction.—McConalogue¹ has shown that for four British coastal stations the monthly duration, T_i , of rainfall at a rate exceeding i , can be expressed in the form:

$$T_i = T_o \exp(-i/\bar{i}) \qquad \dots (1)$$

where T_o is the total duration of rainfall during the period considered and i the average rate while rain was falling. The stations for which detailed figures for T_o are available are few in comparison with those where the total amount of rainfall is recorded; the first part of the present paper gives a method of estimated T_o from the total rainfall (over a period of at least a year) and the location of the station.

McConalogue was concerned with low intensity rainfall only; he does not appear to have examined intensities greater than 10 mm/h (0.39 in/h), and his equation is inapplicable to high intensity rainfall. A new equation is proposed which gives a reasonable fit to experimental data from three British stations over a wide range of intensities.

Yearly duration of rainfall.—Published figures² for the average yearly duration with an intensity of not less than 0.1 mm/h (0.004 in/h) at a number of British stations in 1928–57 have been examined. Each point plotted in Figure 1

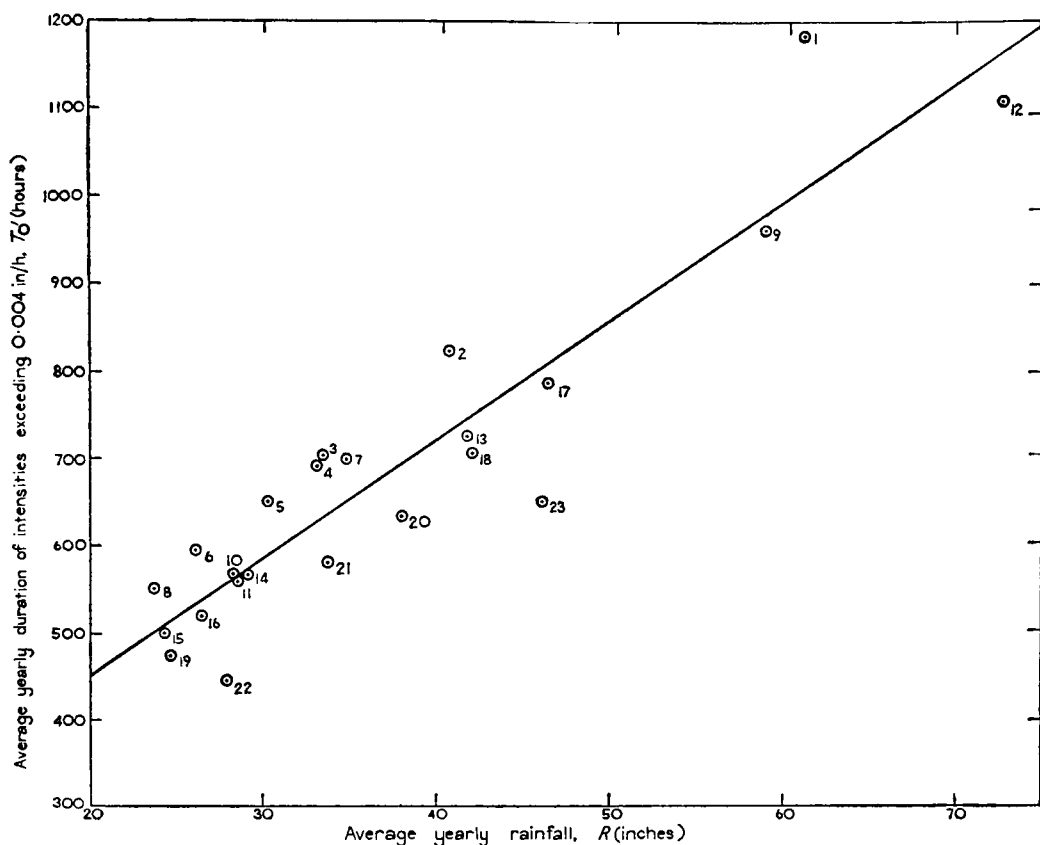


FIGURE 1—RELATION BETWEEN AVERAGE YEARLY DURATION OF RAINFALL WITH INTENSITY EXCEEDING 0.004 INCHES/HOUR AND CORRESPONDING TOTAL RAINFALL

Numbers against plotted points identify stations listed in Table I; the straight line is given by equation (2).

TABLE I—IDENTIFICATION OF STATIONS USED IN FIGURE 1

Number in Figure 1	Location	County	Value of A in equation (4)
1	Eskdalemuir	Dumfries	580
2	Lerwick	Shetland	438
3	Aldergrove	Antrim	400
4	Ashbourne	Staffordshire	388
5	Aberdeen	Aberdeen	383
6	Leuchars	Fife	380
7	Holyhead	Anglesey	371
8	Cranwell	Lincolnshire	366
9	Greenock	Renfrew	311
10	Birkenhead	Cheshire	298
11	Boscombe Down	Wiltshire	285
12	Cray Reservoir	Brecknockshire	284
13	Falmouth	Cornwall	281
14	Felixkirk	Yorkshire	280
15	Stroud	Kent	277
16	Harpenden	Hertfordshire	265
17	Bolton	Lancashire	263
18	Cardiff	Glamorgan	247
19	St. Pancras	London	234
20	Sheffield	Yorkshire	223
21	Southport	Lancashire	218
22	Ross-on-Wye	Herefordshire	133
23	Swansea	Glamorgan	112

relates the average yearly duration in excess of 0.004 in/h (T_o')* to the average yearly total amount (R) for a particular station, a minimum of 15 (and an average of 25) years' records being used for each station; the numbers against the plotted points identify the stations which are listed in Table I. The equation of the straight line, fitted by the method of least squares, is

$$T_o' = 180 + 13.5R, \qquad \dots (2)$$

where the units of T_o' are h/year and those of R are in/year.

The departures of some of the points from the regression line in Figure 1 are not due solely to random variation but are the result of systematic differences between the pattern of rainfall at different stations. This may be seen from Figure 2 where the individual yearly data for Eskdalemuir and Swansea are plotted; the continuous line AE is that given by equation (2). The other continuous lines B, are regression lines through the two sets of data, and it is

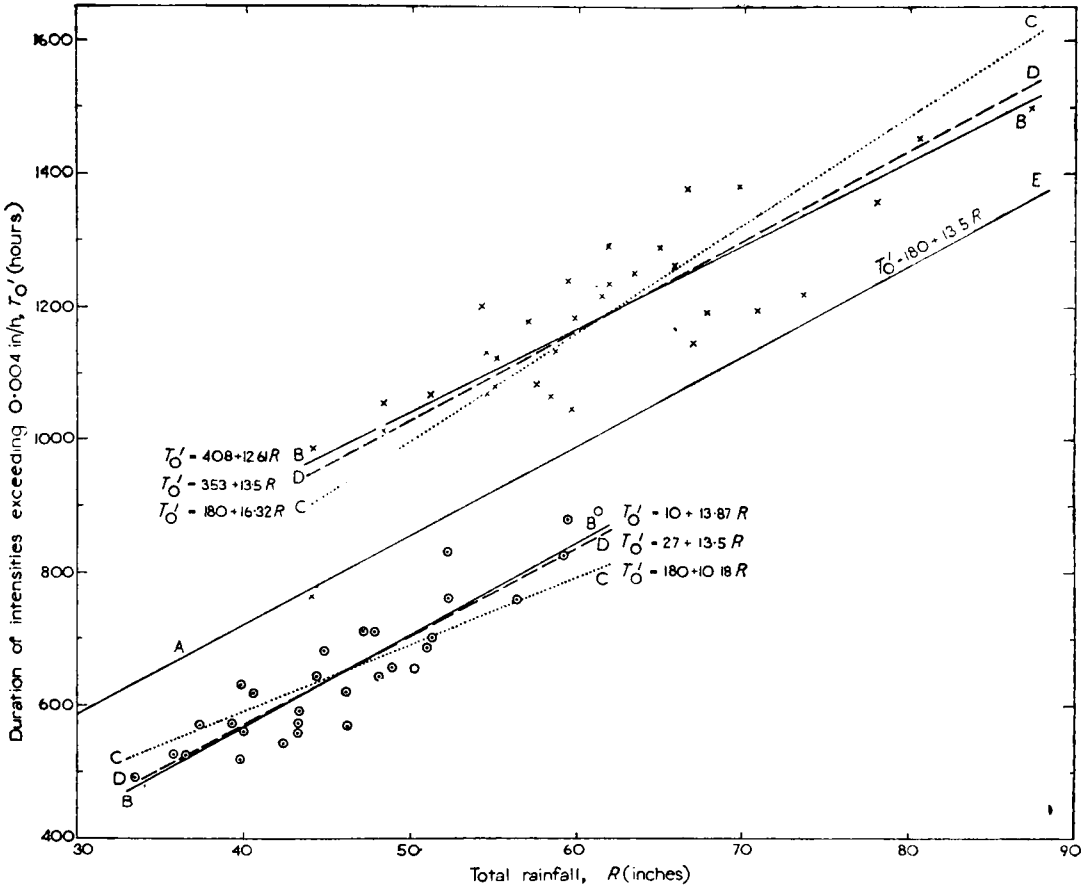


FIGURE 2—RELATION BETWEEN DURATION OF RAINFALL WITH INTENSITY EXCEEDING 0.004 INCHES/HOUR AND CORRESPONDING TOTAL RAINFALL FOR INDIVIDUAL YEARS AT ESKDALEMUIR AND SWANSEA

x Eskdalemuir o Swansea
 — For derivation of straight lines see text

*Rainfall intensities in this paper are expressed in in/h; this particular value of T_i should therefore be denoted by $T_{0.004}$ but, owing to its frequent occurrence, the symbol T_o is used instead

evident that the general form of the relation between the yearly values of T_o' and R for some 30 years at each of these stations is similar to the relation between the long-term mean values of T_o' and R for 23 different stations.

To maintain the form of equation (2) with the minimum alteration, one or other of the two coefficients must be changed to fit the data for individual stations. If the intercept of 180 h is accepted, and the slope of the line is altered so as to pass through the centre of gravity of each of the two groups of points in Figure 2 in turn, the dotted lines C are obtained. Alternatively, accepting the slope of 13.5 h/in and altering the intercept, gives the broken lines D which are almost collinear with the regression lines B. Accordingly it is suggested that equation (2) is more satisfactory written as

$$T_o' = A' + 13.5R \quad \dots (3)$$

where A' varies from station to station and has a mean value of 180 h for the stations listed in Table I.

If it is assumed that equation (1) holds for intensities between 0 and 0.004 in/h, the values of T_o may be calculated from those of T_o' by successive approximations, and equation (3) may then be replaced by

$$T_o = A + 13.5R \quad \dots (4)$$

where A is given by $A - A' = T_o - T_o'$. However, it is shown later that equation (1) is inadequate for representing the distribution of the complete range of rainfall intensities, and the values of A shown in Table I have been calculated as follows: the long-term mean values of T_o' and R from Figure 1 have been substituted in equation (3) to give a value of A' for each station, T_o has been found from T_o' by means of the formula developed later in the paper (equation (9)), and finally $T_o - T_o'$ has been added to A' to give the values of A shown in the table. For a station at which the yearly amount of rainfall (R inches) is known, the yearly duration (T_o hours) may then be estimated from equation (4), the value of A being selected from Table I by consideration of the location of the particular station. Unfortunately there appears to be no systematic variation in the magnitude of A with longitude, latitude, altitude, or nearness to the coast; but an error of even 60 h in A represents an error of only about 10 per cent in the value of T_o for a station with a yearly rainfall of 30 in, and this is probably about the limit of accuracy of equation (4). (Although equation (4) implies that A is the duration of rainfall in a year when no rain falls, this does not invalidate the equation, since within the range of yearly totals plotted in Figure 2 there is no significant curvature in a line drawn through the plotted points.) It should perhaps be mentioned that the experimental determination of values for T_o or T_o' from recorder charts is very difficult and that the results obtained are no doubt sensitive to subjective judgement.

Distribution of rainfall intensities.—In the course of investigations on the flow and composition of storm sewage, the Laboratory installed autographic rain-gauges at Bradford and Brighouse (both in Yorkshire) and at Northampton. The recorders, which are of the type used by the Road Research Laboratory,³ have a chart speed of 6 in/h, and the chart width of 2 inches corresponds to a rainfall of 0.2 in. Intensity distribution curves have been derived from a year's data at each of the Yorkshire stations and from 19 months' data at Northampton. The charts for Bradford were examined by means of a cursor on which were drawn lines with slopes corresponding to intensities of 0.2, 0.5, 1, and 2 in/h; the duration of each period during which these rates were continuously



Photograph by B. J. Burton

PLATE I—NOCTILUCENT CLOUD OBSERVED FROM SOUTH-WEST LONDON AT 0219 UT

ON 21 JUNE 1964

See page 183.



Photograph by G. V. Black

PLATE II—NOCTILUCENT CLOUD OBSERVED FROM KINCRAIG, INVERNESS-SHIRE AT
ABOUT MIDNIGHT ON 5-6 JULY 1964

See page 183.



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PLATE III—WINDOW DISPLAY IN THE NEW LONDON WEATHER CENTRE IN HIGH HOLBORN



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PLATE IV—FORECAST ROOM IN THE NEW LONDON WEATHER CENTRE IN HIGH HOLBORN

equalled or exceeded was measured from the charts, and the total duration of each fall of rain was also noted. The Brighthouse charts were examined in the same way but with additional data being obtained for 0.02 and 0.05 in/h.

The Northampton records were studied in greater detail: the rainfall (to the nearest 0.001 in) during each 3-minute period was read from the charts, and the duration-intensity curve was drawn. For high intensities it was considered that 3 min was too long a period to use for accurate results to be obtained by this method; accordingly, all the periods during which the 3-min intensity exceeded 0.2 in/h were re-examined, tangents were drawn to the recorder charts at intervals of 1 min or less, and the distribution curve was determined from the results. The final distribution is shown by the points plotted in Figure 3 where the results obtained by the former method have been used for intensities up to 0.65 in/h and those by the latter for higher intensities.

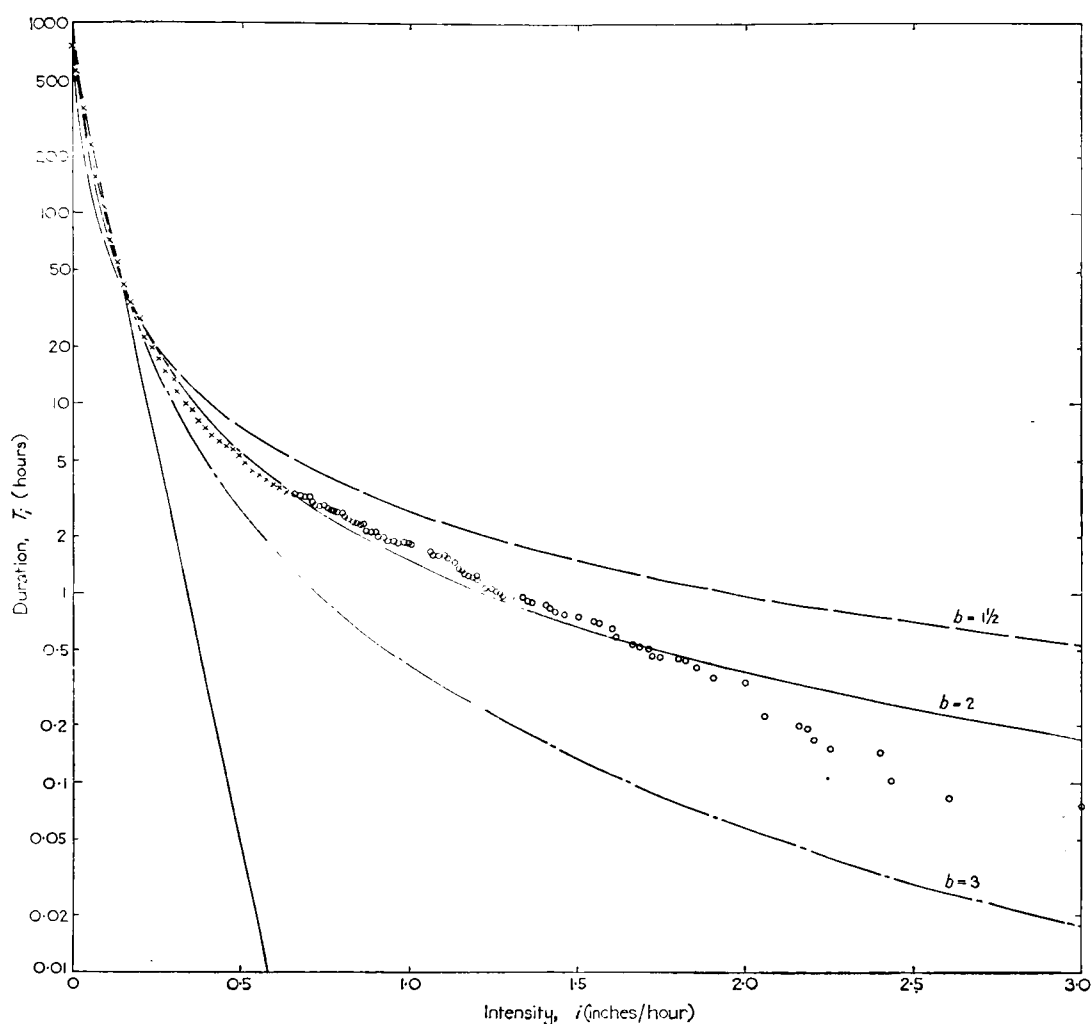


FIGURE 3—DURATION OF RAINFALL INTENSITY EXCEEDING ANY PARTICULAR VALUE AT NORTHAMPTON, JULY 1960 TO JANUARY 1962

Plotted points show observed distribution; curves are those given by equation (5) with the alternative values of b shown above each.

It may be mentioned here that the Northampton data were examined in detail because an attempt is being made to compare the observed distribution of run-off from an impermeable area of 115 acres with that calculated from the rainfall pattern. Once the 3-min rainfall totals had been read from the charts for this purpose, it seemed worthwhile to produce the distribution shown in Figure 3, and then, having found an empirical relation between duration and intensity, to make a cursory examination of the data for the other two sites to see if the relation appeared to be applicable to these sites. In fact, the data for Bradford and Brighouse could have been studied much more fully—there are nearly 3 years' records for each of five recorders—but the detailed examination is very time-consuming and it could not be justified within the scope of the Laboratory's work. However, since so little appears to have been published on the distribution of the whole range of rainfall intensities, it was felt that the results given in this paper might be of interest to other workers.

The straight line in Figure 3 is the expected distribution of intensities as given by equation (1). It is evident that this equation is inadequate for representing the whole range of intensities; it was found that the distribution could best be represented not by an exponential but by a retarded-exponential curve* of the form

$$T_i = T_0 (1 + ai)^{-b}, \quad \dots (5)$$

in which a and b are constant.

Integration of equation (5) must give the total rainfall during the year, thus

$$\int_0^\infty T_i di = \frac{T_0}{a(b-1)} = R. \quad \dots (6)$$

The mean intensity while rain is falling is

$$\bar{i} = R/T_0; \quad \dots (7)$$

substitution of R/\bar{i} for T_0 in the previous equation then gives

$$a = 1/(b-1)\bar{i} \quad \dots (8)$$

so that if a particular value of b is chosen, a may then be calculated.

In Figure 3 the three curves drawn are those given by equation (5) with b equal to $1\frac{1}{2}$, 2, and 3. It should be noted that whereas this equation applies to any period†, the numerical values of A and R in equation (4) are for 1 year. The value of T_0 for substitution in equation (5) was obtained from equation (4) by using the total rainfall for 19 months at Northampton instead of the yearly total R , and by multiplying A by 19/12; the value of A was assumed to be the same as that for Harpenden which is the nearest station to Northampton listed in Table I. It is seen that with b equal to 2 the observed distribution of rainfall intensities is followed with a fair degree of accuracy over the whole range of intensities up to 3 in/h. For this particular case equation (5) reduces to

$$T_i = \frac{T_0}{(1 + i/\bar{i})^2}. \quad \dots (9)$$

The data obtained from examination of the charts for Bradford and Brighouse are shown by the encircled points in Figures 4(a) and (b) respectively. For

*Mr. D. J. Holland, of the Meteorological Office, has pointed out to the authors that a power law fits the higher-intensity data nearly as well as does a retarded exponential.

†This period should best be an integral number of years, as the distribution curves for summer and winter rainfall are found to be markedly different. The 19-month period used here includes roughly equal periods of summer and winter.

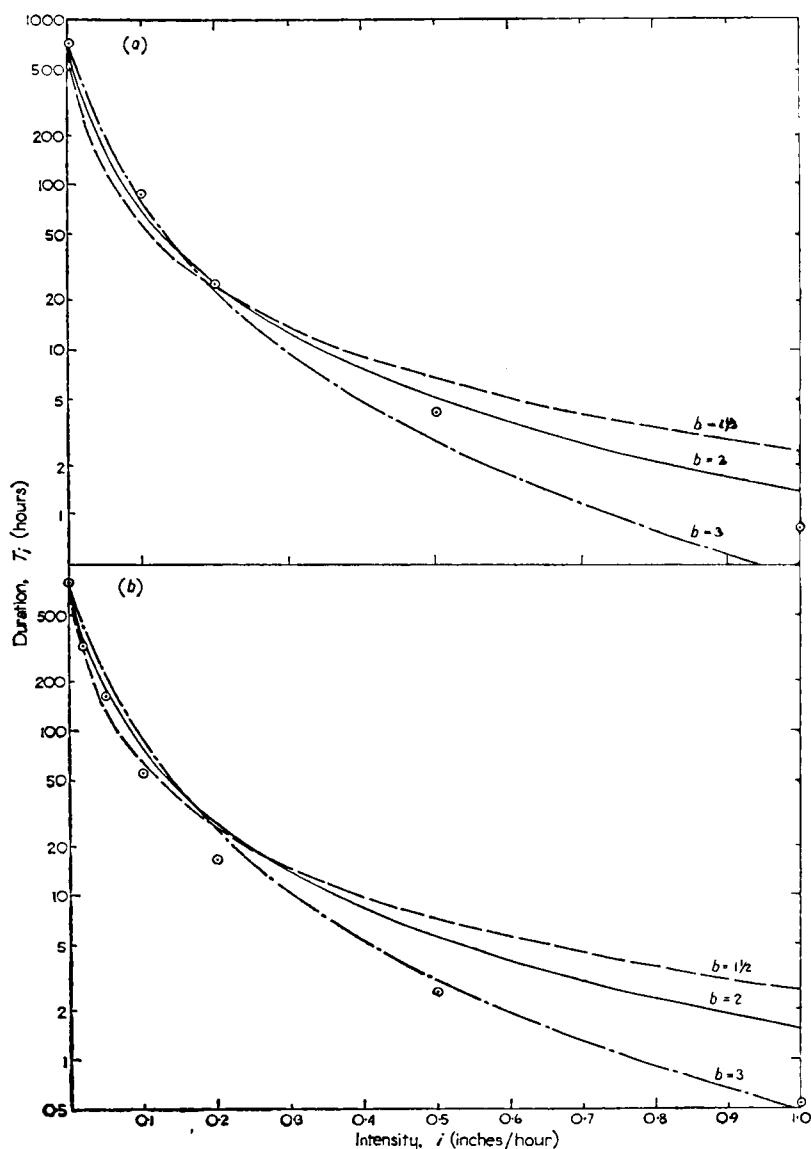


FIGURE 4—DURATION OF RAINFALL INTENSITY EXCEEDING ANY PARTICULAR VALUE AT BRADFORD, FEBRUARY 1961 TO JANUARY 1962 AND AT BRIGHOUSE, JANUARY TO DECEMBER 1960

Plotted points show observed distribution; curves are those given by equation (5) with the alternative values of b shown above each; the straight line is given by equation (1).

(a) Bradford

(b) Brighouse

each of these sites the value of A for use in equation (4) has been taken as the mean of the values for the three nearest stations listed in Table I. The three curves in each of these diagrams correspond to those shown in Figure 3. For Bradford it is seen that with b equal to 2 the experimental data are fitted reasonably well, but at Brighouse the curve for b equal to 3 is distinctly better for the two highest intensities plotted—though none of the curves can be considered to fit the whole range of data very satisfactorily.

Discussion.—Figures 3 and 4 show that equation (9) (that is, equation (5) with b equal to 2) gives a reasonable approximation to the distribution of intensities at the three sites studied. For intensities up to 1 in/h the ratio of the

observed to the calculated durations at Northampton lie within the range 0.78–1.25; the corresponding ranges for Bradford and Brighouse are 0.60–1.25 and 0.35–1.19. Although these last two ranges indicate large errors in the predicted values, the range of durations covered is very great, the largest duration being over a thousand times the smallest. At Brighouse—the station giving the greatest errors in prediction—the observed and calculated values of T_0 (the total duration of rainfall) were 784 and 658 h respectively, whereas the corresponding values of T_1 (the duration of intensities exceeding 1 in/h) were only 0.5 and 1.5 h; at Northampton—for which site the data for a longer period (19 months) were examined—the observed and calculated values of T_0 were 763 and 973 h respectively, and those of T_3 were 10 and $4\frac{1}{2}$ min.

No simple equation can reasonably be expected to give greatly better predictions than does equation (9): statistical fluctuations in high intensity rainfall must give rise to corresponding variations in the yearly duration of such rainfall even at a particular station in two years with substantially the same total rainfall.

Conclusion.—It is suggested that, when information is required concerning the probable yearly duration, T_i h, of rainfall intensities exceeding any particular value, i in/h, at a station where the annual rainfall is R in, it can be obtained approximately from the equation

$$T_i = \frac{T_0}{(1 + i/i)^2}$$

where $\bar{i} = R/T_0$, and $T_0 = A + 13.5R$, the value of A being selected from Table I.

Acknowledgements.—Miss J. M. Threlfall carried out the detailed examination of the Northampton rainfall records and I. C. Hart assisted in much of the subsequent work.

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NOCTILUCENT CLOUDS IN 1964

551.593.653

By J. PATON

The accompanying Table I contains an analysis in summary form of displays of noctilucent clouds that were visible over western Europe and the Atlantic during 1964.

The geographical situation of the clouds was determined by the method described in an article in the *Meteorological Magazine*¹. Those occasions when the cloud mass was seen to be illuminated to its southern border at some time during the night are recorded in the table. The extension in longitude is given to the nearest 5°.

The most striking displays occurred during the nights of 20–21 June, 30 June–1 July, 5–6, 11–12, 15–16 and 19–20 July. The last of these displays became spectacular only during the latter part of the night after 0045 Universal Time (UT). The changes in blue and green coloration and the rapid variations in fine

structure and form recorded by observers accord with the theory that these are ice clouds, in fact, very high cirrus, formed on nuclei of cosmic origin. If this is so, then the formation of the clouds is largely controlled by the temperature at the mesopause. The fact that the frequency of occurrence of the clouds during the year of sunspot minimum, 1964, is the greatest recorded since systematic observations began, suggests therefore that the temperature at the mesopause reaches a minimum at the time of sunspot minimum. From observations at the extensive network of stations that he has organized over North America, Benson Fogle of the University of Alaska reports that during 1964, noctilucent clouds were seen as early as 1 April and as late as 31 August, and that during the period 28 June–4 August, the clouds were seen somewhere over North America on every night except 2–3, 3–4, 9–10, 14–15, 18–19 and 19–20 July. It will be noted that on three of these nights—2–3, 9–10 and 19–20 July—the clouds were seen over western Europe.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND ATLANTIC IN 1964

Date— night of	Times UT	Approximate geographical position		Notes by observers
		Latitude*	Longitude	
9–10 June	2310–0140	57°	5°E–20°W	Silvery streaks and patches, blue edges.
10–11	0020–0035		0°	Seen through temporary break in overcast sky at elevation 9° above northern horizon in latitude 56°.
14–15	0010		0°	Bluish streaks seen through break in cloud at elevation 4° in latitude 56°.
15–16	0200–0405		30°W–55°W	Reports from two aircraft over the Atlantic. Long bluish streaks with fine ripples. Elevation 5° in latitude 52°.
20–21	2245–0235	< 51°	5°E–15°W	Very bright display with long and closely-packed parallel filaments and fine rippled structure. Portions very blue at times (see Plate I).
24–25	2355–0120	60°	10°E–10°W	Weak and isolated patches just perceptible in very clear and cloudless conditions.
27–28	2300–0235	< 60°	10°E–20°W	Compacted fine streaks, portions of strong blue colour.
28–29	0030		0°	Seen in gap in low cloud at elevation 11° in latitude 56°.
29–30	2215–0400	< 57°	20°E–55°W	Long streaks of pearly-white cloud tinged with blue. Reports from western Atlantic to Denmark.
30 June– 1 July	2310–0345	53°	5°E–60°W	Faint streaks and patches at first. Brighter and complicated ripple patterns after 0100 UT. Two observers independently report colour as greenish-white.
2–3 July	0010–0100		5°W–10°W	Reports from two aircraft. Elevation 10° in latitude 56°.

*Of southern borders when measurable.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND ATLANTIC
IN 1964—*contd.*

Date— night of	Times UT	Approximate geographical position Latitude* Longitude		Notes by observers
4-5	0005-0040		0°	Very faint streaks to elevation 8° in latitude 56°.
5-6	2120-0420	< 55°	0°-70°W	A brilliant display, situated to the west of longitude 0°, visible in the north-west from Denmark. Long straight band extending overhead from just west of the outer Hebrides, in a direction a few degrees to east of north to 250 km west of Shetland. This band, occasionally splitting in parts and showing fine wave structure, persisted from 2220-0040 UT moving slowly westwards. The band was described by many observers as remarkably like an aeroplane condensation trail, bluish in colour. A mass of chaotic streaks, aligned approximately north-south, overhead north of latitude 57° (probably lower) in the region bounded by longitudes 0° and 3°W, at 2220, also moving slowly westwards; this weakened after 2340 and had vanished by 0020 UT. By 0050, the noctilucous cloud over western Europe had vanished. Observing conditions remained good at several stations until 0230, but no further cloud was seen. The cloud was later reported by Lufthansa officers over the western Atlantic to Nova Scotia.
6-7 July	2300-2325		0°	Aircraft in latitude 55° report two streaks at elevation 5° and 7°, bluish-silvery-white in colour. Earlier at 1855-1910 UT a pilot from the same squadron, flying at 44,000 ft above Leuchars (56°N) reported two thin silvery streaks, one at 8° elevation, the other at 10° elevation. This was, of course, in bright daylight, the sun being at an elevation of 20°.
9-10	2225-2255		15°E-10°E	Report of short-lived display from Denmark. Nil visible in the U.K. in good observing conditions.
10-11	2210-2300		15°E-5°E	Streaks up to elevation 12°, visible from Denmark (56°N 9°E)
11-12	2245-0140	52°	15°E-15°W	Silvery-white streaks, tinged with blue, almost as bright as moonlit cumulus. Areas of fine complex wave structure in almond-shaped patches. Turbulent in eastern portion of display.
12-13	2310 and 0440		5°E and 70°W	Seen through broken cloud, elevation 15° in 56°N 5°E, and to elevation 10° from aircraft in 50°N 70°W.
15-16	2110-0140	< 56°	15°E-25°W	Mainly in lenticular patches, silvery white, occasionally with bluish tinge and herring-bone structure. General movement westwards. Several observers reported greenish colour in later stages. Brightest at 0040 UT.

Date— night of	Times UT	Approximate geographical position		Notes of observers
		Latitude*	Longitude	
19–20	2230–0240	55°	5°E–10°W	Faint until after 0045 UT, developing thereafter into widespread compacted mass of moderately bright clouds, showing complicated wave patterns.
25–26 July	0050–0220 and later over mid- Atlantic		5°E–40°W	No trace of cloud until 0050 UT when weak filaments became visible in latitude 56° to 12° elevation. Faint and pale blue in colour. Aircraft in 56°N 38°W and 60°N 25–30°W reported noctilucent cloud without giving details.
30–31	0125–0230		5°E–0°	Faint clouds seen up to elevation 16.5° in latitude 58°.
2–3 Aug.	0300–0330		25°W–35°W	Noctilucent cloud observed to 10° elevation from aircraft in latitude 58°.
6–7	2355–0145		20°W	Noctilucent cloud observed in Reykjavik (64°N), Iceland. No details.

*Of southern borders when measurable.

The clouds have never been seen from stations in central Scotland later than 3 August. They have been regularly seen at later dates in higher latitudes, for example on 6–7 August in Reykjavik in 1964. This northwards recession of the clouds in early August may indicate that the temperature at the mesopause in the lower latitudes has now begun to increase from the normal summer minimum².

This analysis has been compiled from observations made (a) at Malin Head and by staff at Meteorological Office stations at Lerwick, Wick, Kinloss, Dyce, Tiree, Shanwell, Leuchars, Renfrew, Carlisle, Acklington, Manby, Ronaldsway, Linton-on-Ouse, Leeming and Exeter and in O.W.S. *Weather Surveyor*; (b) by the following voluntary observers—R. J. Livesey, Newton Mearns; C. F. Priestley, Dunoon; C. Wilson, Dr. H. Lang and C. M. Christison, Newton Stewart; Dr. D. A. R. Simmons, Aberdeen; K. B. Hindley, Douglas; J. W. Noble, Leuchars; F. J. Acfield, Northumberland; G. V. Black, Inverness-shire; B. J. Burton, London; P. C. Knowles, Whitstable; Miss H. L. Tuer, Oxford; P. Puxty, Folkestone; J. R. Randall, Pickering; J. O. Oleson and G. Persson, Denmark; and Dr. T. Saemundsson, Iceland; and (c) by observers in aircraft—Flight Lieutenants Fletcher, Steele-Morgan, Penfold and Quantrill, and Flight Sergeant Faulkner of the Royal Air Force; Captain Miles and Lee, B.O.A.C.; Captain Mountney, B.E.A.; and Captains Tinbergen, Ebert and Arzinger and Navigators Liegnitz and Kuppert of Lufthansa. Dr. F. E. Volz of the University of Tübingen collected and sent the observations from Lufthansa aircraft. Some observations of particular displays were received from observers, mainly in aircraft, who did not give their names. Photographs were supplied by G. V. Black, Dr. H. Lang, B. J. Burton, C. Wilson and C. M. Christison (see Plates I and II). We wish to thank all who have taken part in this work either by organizing or making the observations.

These synoptic studies will continue and we invite the co-operation of observers who may wish to join in contributing to them. Notes on observation and photography of the clouds can be obtained from the Balfour Stewart Laboratory, The University, Drummond Street, Edinburgh 8.

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551.524.36

PHENOMENAL TEMPERATURE OSCILLATION IN ADEN

By G. FROUDE and J. SIMMONDS

Large temperature changes occur from time to time in a number of different parts of the world, and some of the areas and circumstances in which these changes take place have been indicated in a memorandum by Dods and Dinsdale.* Although the examples quoted in the memorandum record temperature rises (or falls) much greater than in the instance described in the present note, there is no mention of a case where a sudden temperature change was followed in a very short time by a return to near the former value, and the details given below may, therefore, be of some interest.

On 29 June 1964, the temperature recorded at the Main Meteorological Office, RAF Khormaksar, (13°N 45°E), reached a typical maximum of about 98°F (37°C) in the middle of the day, and subsequently the usual fairly sharp diurnal fall set in to reduce the temperature to about 88°F (31°C) by 1630 GMT, by which time it was already dark. (Times in this note are GMT; to obtain Aden local time add three hours.) The surface wind had been light easterly for some time. At 1700 GMT, however, in a 'hot blast' of air the temperature rose almost instantaneously to 107°F (42°C) as measured by the maximum thermometer in the screen. About the same time, the wind backed from 090 degrees 5 knots to 220 degrees 5 knots, subsequently increasing sharply to about 20 knots and veering to a mean north-westerly direction (but with fluctuations between 230 and 040 degrees) with a gust of 32 knots at 1703 GMT. Within five minutes, the dry-bulb temperature had fallen again to 87°F (31°C), while the surface wind veered once more to 090 degrees 10 knots.

The synoptic charts for the day showed a depression over Persia, with a trough to the east of Djibouti, and the intertropical convergence zone, though very ill defined, seemed to lie a little to the south of Aden at 1800 GMT. A thunderstorm had been reported during the afternoon in the Thumeir area, about 50 miles north of Aden, but the upper winds between 12,000 and 18,000 feet observed on the midday Khormaksar ascent could have advected the storm towards Aden.

It is thought possible that a trough or squall line associated with the Thumeir thunderstorm may have swung round and approached Aden from the north-west shortly before the 'hot blast' occurred, especially as there was an increase of medium cloud and a little rain about that time. Two aircraft found severe turbulence at 2700 to 3500 feet between 11 nautical miles west of Khormaksar and about the same distance east of the aerodrome, one aircraft also reporting

DODDS, L. and DINSDALE, F. E.; Air temperature and its variability. *Invest. Div. Memor. No. 96*, 1964 (unpublished, copy available in the Meteorological Office Library).

heavy rain. The 'hot blast' was likened by a forecaster, coming on duty, to the sudden opening of an oven door. It was also felt at Steamer Point, some 6 miles away.

A plausible explanation substantiated by the turbulence report given below, is that a down draught associated with the supposed squall line forced air in the layer 850 to 900 mb, down to the surface. Such air descending adiabatically from 850 mb to 1000 mb would warm to about 44°C (111°F) with a wet-bulb temperature of 20°C (68°F). Consideration of the 2330 GMT ascent for 29 June (Figure 1) shows that the 850 mb wet-bulb potential temperature was 21°C as compared with a surface wet-bulb temperature of 28°C.

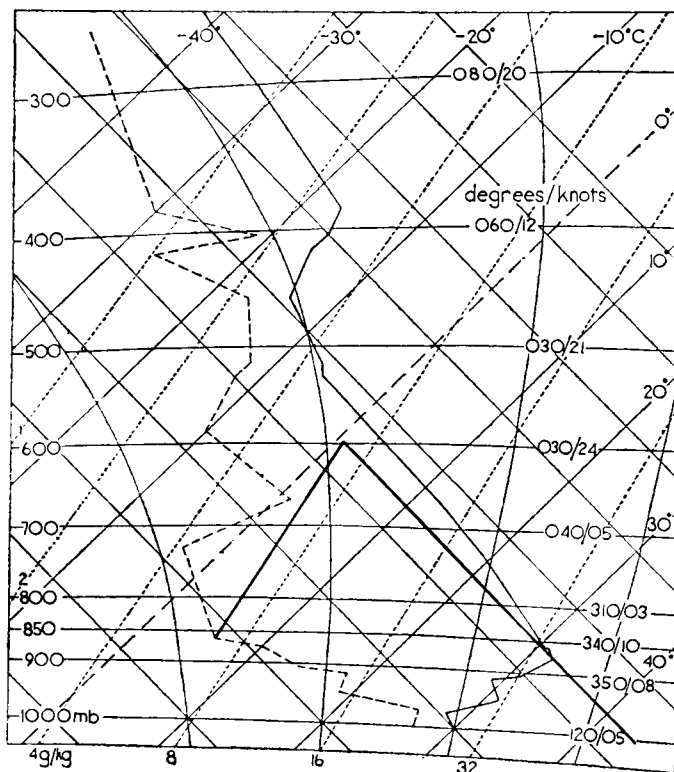


FIGURE 1—UPPER-AIR ASCENT FOR KHORMAKSAR AT 2330 GMT ON 29 JUNE 1964
 ——— Dry-bulb temperature - - - Dew-point
 Bold construction lines show that the wet-bulb potential temperature at 850 mb is 21 C

The maximum temperature reached on this occasion has been exceeded in Aden, though it may well be a record for this time after sunset. The highest maximum between 0600 and 1800 GMT since 1946 was 44°C (111°F) in 1961 during a sandstorm on 29 June—strangely enough on the same date as the recent oscillation.

Turbulence report.—A pilot flying an Argosy aircraft near Little Aden at a distance of 10 to 15 nautical miles from Khormaksar and heading east towards Khormaksar shortly before 1700 GMT reported very severe turbulence. The aircraft, flying at 3500 feet, had just encountered a little rain and some dust which temporarily obscured the windscreen, but at no time was the aircraft in cloud. The aircraft suffered a 'terrific jolt' and suddenly dropped from 3500 to 2700 feet in altitude.

The pilot made an immediate attempt to regain his previous altitude but because of continuous very severe turbulence he had extreme difficulty in maintaining control. The indicated airspeed fluctuated between 140 and 195 knots. On reaching the airfield beacon at Hiswa, about 5 miles from Khormaksar, the aircraft was 'carried up' to about 3500 feet once more. The surface wind speed over the airfield at the time was 2 knots.

Autographic records.—The bimetallic thermograph and hair hygograph in the instrument screen at Khormaksar responded well to the short-lived changes in temperature and humidity as shown in Figure 2. The records from the mercury-in-steel wet- and dry-bulb thermometers (Figure 3) located in a small screen 20 yards distant from the main instrument screen, and separated from it by the hydrogen shed, showed differences which are most likely due to the lag of this instrument. The mercury-in-steel instrument

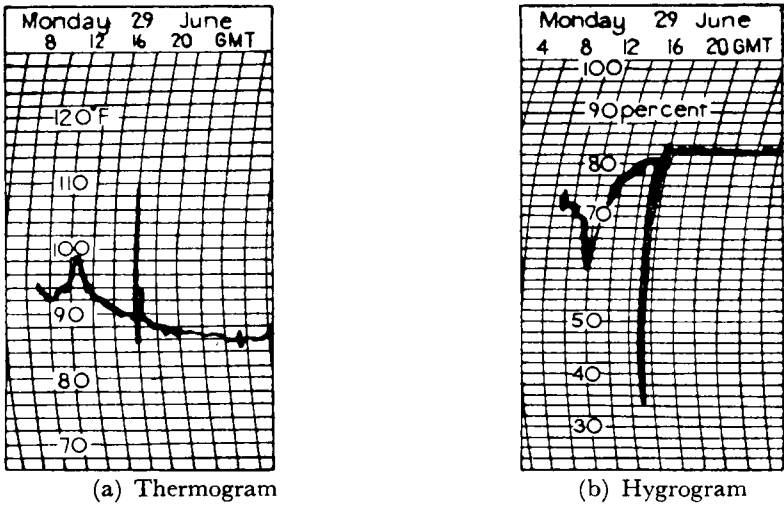


FIGURE 2—AUTOGRAPHIC RECORDS FOR KHORMAKSAR ON JUNE 29 1964

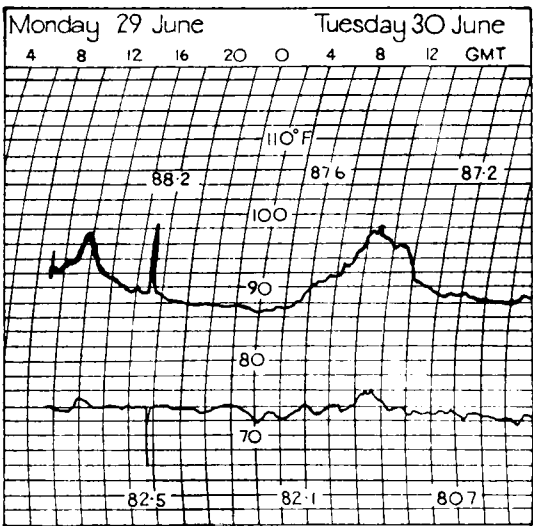


FIGURE 3—THERMOGRAM FROM THE MERCURY-IN-STEEL RECORDER AT KHORMAKSAR ON 29-30 JUNE 1964

Upper curve gives dry-bulb temperatures, lower curve (set 10 low) gives wet-bulb temperatures

recorded a rise in temperature of 9°F (5°C) to 98°F (37°C) and a fall in wet bulb of 8°F (4°C) to 75½°F (24°C) (corrected values), giving a relative humidity of 33 per cent. This agrees closely with the adjusted reading of the hair hygograph of 31 per cent, as the hygograph may also be expected to lag considerably under the circumstances. However, assuming a fall in wet-bulb temperature of 8°F (4°C), and an actual maximum dry-bulb temperature of 107°F (42°C), then the relative humidity fell to about 20 per cent for a brief period.

METEOROLOGICAL OFFICE DISCUSSION

The work of the Central Forecasting Office

The Monday Discussion held in January 1965 was opened by Mr. V. R. Coles. He described the international and national aspects of the work of the Central Forecasting Office (CFO), stressing the services provided for the Meteorological Office outstations. The recently revised land-line facsimile programme was described in some detail. Mention was made of the land areas and shipping forecasts provided for the BBC and for the national Press as well as the variety of other services provided by CFO such as the summer fine-spell notification service for farmers.

Mr. Coles detailed the allocation of duties to the team of forecasters at CFO before describing changes in the CFO routine that would be effected in the relatively near future. The first and most important of these will be the introduction into the CFO routine of numerical forecasts which will be prepared twice a day after the new computer COMET has been installed. Another development that is expected during 1965 and early 1966 is the introduction of automatic plotting for the hourly charts of the weather of the British Isles which are transmitted to the outstations on the land-line facsimile circuit. The automatic plotter will plot two stations a second and will operate on the teleprinter tapes as received at Bracknell from the principal and main meteorological offices. It is hoped that it will be possible to transmit these charts to the outstations at least 20 minutes earlier than is now possible. Mr. Coles' next reference was to equipment which would enable direct read-out of satellite cloud pictures to be made at Bracknell. It is hoped that it will be possible to broadcast these pictures on the facsimile circuits. Finally Mr. Coles described the development by which it is hoped to broadcast two isopleth charts on the facsimile circuits in 5 minutes. These charts will be received at the outstations on a scale of 1:30,000,000.

During the general discussion, which ranged over many topics, officers from the outstations had an opportunity to express their opinions of the work of the Central Forecasting Office and several useful suggestions were put forward which will be of assistance in future planning.

NOTES AND NEWS

London Weather Centre moves to High Holborn

The London Weather Centre had been accommodated since 1959 at the southern end of Kingsway in Princes House. This is an old building of eight storeys whose roof exposure had been suitable for both eye and instrumental weather observations.

Length of tenure was in doubt and then, in 1962, it was learnt that an adjacent building was to be demolished and replaced by a new building at least 50 feet taller than Princes House, the roof of which would then no longer be suitable for instruments and, in particular, weather radar. This made it necessary for new accommodation to be sought.

This was no easy matter for the Ministry of Public Building and Works because the new accommodation had to satisfy certain conditions. In particular, the roof should be suitably exposed for instruments and observations and high enough so that future development would not impair the suitability of the site for observations. Moreover, it should be within easy reach of Fleet Street. Eventually the Ministry came up with part of a new building at 284–286 High Holborn, opposite State House. As the roof of the Weather Centre building is overshadowed by State House, instruments have been installed on State House, with cabling under High Holborn to recording and indicating instruments in the Weather Centre. Although the roof of State House was considered suitable for meteorological instruments, present and future building development in London made it suspect as a site for weather radar. This led to the exciting use of the GPO tower in Bloomsbury as a site for the radar scanner, thanks to the co-operation of the Postmaster General.

The new accommodation which was occupied on 9 January 1965 has a contemporary shop front in keeping with the general style of the building itself (see Plates III and IV). A large magnetic chart showing weather over the British Isles, the near continent and adjacent seas occupies a considerable proportion of the window display. Near it are three charts showing the synoptic situation of yesterday, today, and tomorrow. An additional display of topical interest occupies part of the window together with details of sunrise and sunset times and moon data. There is an open-scale barograph and dials showing wind speed and direction, temperature and relative humidity as measured on the roof of State House. In an adjacent window details of the weather at a number of British and continental holiday resorts are displayed.

Immediately behind this window and next to the 'shop' is the broadcasting studio. This room, from which the morning 'Metcast' and other broadcasts are made, is soundproofed and designed for easy conversion for use as a television studio should the need arise. Nearby are two small rooms, one housing duplicating equipment, and the other, radio and television monitoring and recording equipment.

Adjoining these rooms is the forecast room which is dominated by the forecasters' and plotters' bench. At this large and complex piece of furniture 8 to 10 people are able to cope with the stream of inquiries from the general public. In the Kingsway Office the bench had 6 positions with a 10-line key and lamp unit at each. The number of calls dealt with has more than doubled in the last 6 years and on some occasions the calls have been too numerous to deal with (Figure 1). The new bench provides 8 positions at which 4 forecasters and 4 assistants may carry out their routine work as well as answering telephone calls on the 20-line key and lamp unit provided for each. Eleven of these 20 lines handle calls from the general public on Temple Bar 4311 while the remaining 9 provide direct links with Ministry of Defence exchanges, Central Electricity

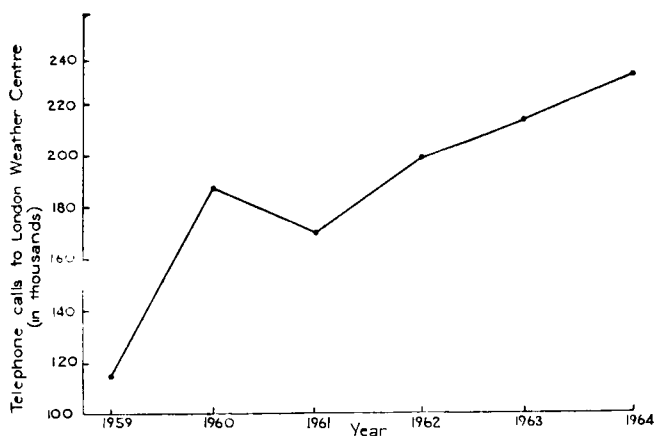


FIGURE 1—NUMBER OF TELEPHONE CALLS TO THE LONDON WEATHER CENTRE 1959-1964

Generating Board Control Rooms and the GPO. The last is used to provide the GPO with forecasts for London and the coasts of south-east England for use in the Automatic Telephone Weather Service.

A new instrument console has been designed, incorporating a distant-reading temperature recorder, a high-speed anemograph and a precision aneroid barometer. The instrument panel is above a desk at which the observer records readings in the *Daily Register*. Nearby is Meteorological Office data logging equipment for recording solar radiation. Also in this room is the display unit of the weather radar. Next to this room, with easy access, are the teleprinter room and the typing pool.

At the rear lies the 'Climate' room. Here are housed records and other information for the weather of the past century. Tables are provided at which visitors may work when extracting items from the records. In this room records are maintained for a number of stations throughout Great Britain, and here the summaries of weather are prepared and issued weekly and monthly.

J. GEORGE

REVIEWS

Heat transfer in the soil by A. F. Chudnovskii (translated from Russian). 9½ in × 6½ in, pp. iv + 164, illus., Israel Program for Scientific Translations, Jerusalem. (Distributed by Oldbourne Press, 121 Fleet Street, E.C.4), 1962, Second impression 1963. Price: 48s.

This book, unlike its companion translations^{1,2} from the Russian, is not an introduction to the subject for the beginner; nor is it indeed a textbook, like *Physics of Plant Environment*,³ because it is not a comprehensive and integrated exposition of the subject. Here is an account of the practical and theoretical contributions to research on the subject of heat transfer, both in the soil and in the air near the air-soil boundary, by an author who is an experienced micro-meteorologist and soil physicist.

The first two chapters (about one third of the book) contain theoretical discussion of the surface energy balance with special reference to soil heat transfer but little or no discussion on the 'minor' processes, such as percolation or heat transfer in the vapour phase.

Chapter 3 (another third of the book) discusses the classical methods of obtaining soil diffusivity and the problem of more general (non-periodic) surface temperature variation; field and laboratory measurements of soil temperature, using plate and cylindrical rod, isothermal and instantaneous heat sources; and the theoretical derivation of soil thermal conductivity ('calometric conductivity') and soil diffusivity ('thermometric conductivity').

Chapter 4 deals with the dependence of soil thermal characteristics on soil physical and chemical properties, soil temperature and humidity; and the following chapter gives a mathematical derivation of soil temperature as a function of depth.

The final chapter (6) describes two practical applications: (i) the determination of soil moisture content from thermal characteristics and (ii) of special interest to meteorologists, the forecasting of minimum night-time radiation frost temperature using temperatures at sunset and at 7 p.m., the radiation balance, wind speed and soil humidity and constants which depend on the time and place of observation. The radiation balance parameter is obtained from tables, using air temperature, humidity and cloud cover; soil humidity is broadly classified as 'dry, slightly moist or moist.' If a forecast is regarded as successful when the difference between the observed and calculated minimum temperature is $\leq 2^{\circ}\text{C}$, half-successful for larger differences $\leq 3.4^{\circ}\text{C}$ and unsuccessful for difference $\geq 3.5^{\circ}\text{C}$, then the success of these forecasts is claimed to be 80 per cent or more for all days, and 90 per cent or more for all days excepting days with advection.

The account includes considerable mathematical detail and in Chapter 3, experimental techniques are dealt with at length.

The book was originally published (in Russian) in 1948 and is therefore somewhat out of date. This is apparent, for example, from the references to the state of research on the mechanism, measurement and calculation of evaporation (p. 19), the lack of suitable maximum and minimum soil thermometers (p. 59) and the section relating soil diffusivity, etc. to soil humidity (pp. 123-128). Also since 1948, there has been important development in the direct measurement of all the major terms of the surface energy balance—soil heat flux, atmospheric fluxes of heat and water vapour and net radiative flux.

The presentation suffers from the lack of an index and of bolder-typed sub-headings and from a number of misprints or omissions, mainly obvious but sometimes disconcerting. Non-Russian references are limited and some references in the text are omitted from the bibliography.

Despite the faults mentioned, the book is a useful contribution by a valuable translation service and its acquisition should benefit any science library catering for soil physics or micrometeorology.

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E. N. LAWRENCE

Climatology—an introduction, by J. Bucknell. 8 $\frac{3}{4}$ in \times 5 $\frac{3}{4}$ in, pp. xii + 163, *illus.*, Macmillan & Co. Ltd., St. Martin's Street, London, W.C.2, 1964. Price: 18s.

This book is aimed at sixth form pupils and others studying climatology at post "O" level stage. No doubt the author envisages its use by the teacher working with the class; it might prove rather indigestible to the student working on his own at this level.

Chapter I—Factors of Climate—forms a useful introduction to the subject, though a more quantitative approach might be enlightening. For example the idea of insolation is introduced, but the word is never defined nor are any suitable units of measurement suggested. Diagram 1.1 illustrates how short-wave radiation from the sun is reflected, scattered and absorbed by the earth-atmosphere system, but gives no idea of what proportion is reflected or is available for heating the ground. In the second chapter the general circulation is described briefly and the idea of stability of an air mass introduced. Here a lot of ground is covered though, of necessity, the treatment is somewhat cursory. This is no doubt adequate as a reminder to the student with a sound basic knowledge of meteorology but the less well-prepared reader will almost certainly need to refer to a suitable textbook on elementary meteorology.

The third chapter provides a short but clear account of the historical approach to the problem of climatic classification, finishing up with a description of the classification due to Professor Miller. The following eight chapters, comprising some two thirds of the total text, take the reader through examples of the various types of climate recognized in Miller's classification. Virtually the whole land surface of the earth receives some mention. It would be helpful here if, in a subsequent edition, the author were to include a few worked examples showing how, from statistics of temperature and rainfall, any particular station can be assigned a climatic classification. The reader would then be in a position to construct his own climatic atlas from the tabulated data normally available. The reviewer would also prefer to see latitude, longitude and altitude quoted for each station mentioned in the diagrams rather than a vague location stated such as "Congo basin" or "West Africa." A short final chapter relates climate to vegetation; this relationship is essential to the idea of climatic classification and the chapter could with advantage be placed earlier in the book.

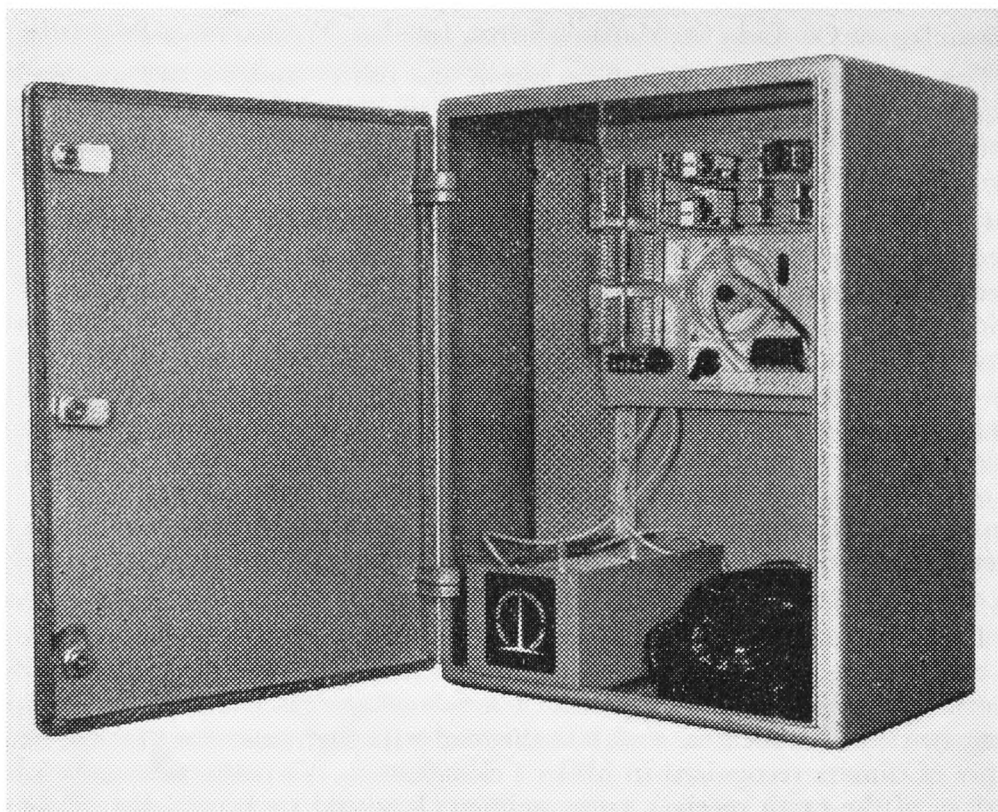
The text is well illustrated by close on 200 diagrams. Those including a map would be even more helpful if a grid of latitude and longitude were added. The book cannot be considered easy reading, containing, as it does, a mass of information, but any reader who works his way through chapters 4 to 11, supplementing his reading from regional textbooks will emerge with a sound knowledge of the distribution of climatic types over the globe. A set of questions and exercises is included, but not the answers, as stated on the book jacket. A useful bibliography and an adequate index are also provided.

H. HEASTIE

OBITUARY

Mr. H. W. L. Absalom, O.B.E.—It is with deep regret that we heard of the death of Mr. H. W. L. Absalom on 7 April 1965. An appreciation of his many years of service in the Meteorological Office appeared in the August, 1959 (page 248) issue of this magazine. Our deepest sympathy is extended to his widow and family in their sad loss.

D.J.W.



NEW THORN RAINGAUGE TELEMETRY APPARATUS FOR METEOROLOGICAL OFFICE

This new Thorn apparatus allows an unattended Meteorological Office tipping bucket raingauge to be read via the public telephone system.

The apparatus is wired directly to the raingauge relay. It receives a pulse for each standard amount of rainfall registered, adds them in decimal form and stores the answer as a number of pulses in units, tens and hundreds.

The extension number may be dialled from any other extension. A recorded announcement giving identification is heard, followed by coded tone pulses corresponding to the decimal number stored. The telephone answering unit then resets in readiness for the next call. Telephone interrogation does not alter the state of the digit store in any way.

The Thorn Raingauge Telemetry Apparatus comprises equipment for telephone answering, timing and switching, digit reading and tone sending, raingauge impulse counting and storing. The transmitter is housed in a robust waterproof case with self-contained power supply.

It was designed by the Meteorological Office and engineered and manufactured by Thorn Electronics Ltd.

The G.P.O. has approved the connection of this equipment to the public telephone system
Meets Met. Office specification SR46-1964



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SOME ASPECTS OF SATELLITE METEOROLOGY

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Introduction.—The use of artificial satellites to observe the atmosphere and the earth's surface from above may be fundamental to the solution of many problems in forecasting and research, provided that the full potential of the observations is recognized, evaluated and used. Cloud photographs and infra-red measurements have been made from the American satellites of the Television and Infra-red Observation Satellite (TIROS) series and the observations, which are still continuing in this experimental phase, have been shown to be of great value, both as direct forecast aids and as research data. This paper gives a brief description of the American satellite programme as a whole and of the capabilities of the satellites. The data from experimental and operational satellites are also discussed in relation to forecasting services and to research.

The satellite programme.—The experimental phase of satellite meteorology began with the launching by the United States of TIROS I in April 1960. Several TIROS satellites have since been launched and have carried different combinations of wide-angle and medium-angle television cameras and infra-red scanning systems. All the TIROS satellites have carried an advanced vidicon camera subsystem capable of producing and storing television pictures which have a resolution of about a mile. (A vidicon is a small television-type tube.) The experimental phase is now being concluded with the TIROS VII, VIII and IX satellites, which are still in orbit and from which television pictures are being received at ground stations in the United States (see Plate I). Within a few hours of being received the pictures are analysed and distributed internationally as nephanalyses, i.e. coded or facsimile analyses of the organization of clouds. The reduction and use of data obtained from the TIROS meteorological satellites are described in World Meteorological Organization Technical Note No. 49.¹

In September 1964, additional experimental data were also obtained for a few weeks from a more advanced meteorological satellite—NIMBUS A. The next step, however, will be to launch a series of satellites to give regular world-wide coverage. The series will be known as the TIROS Operational Satellite system (TOS) and the first launching is expected in late 1965. It will be based on the proven TIROS meteorological satellite travelling in a polar orbit designed to give a northward crossing of the equator about every 113 minutes at local noon. In 12 hours every part of the earth will come within the field of view of the cameras so that photographs of a series of overlapping strips of the earth will be obtained during successive orbits.

TIROS VIII and NIMBUS A also carried an automatic picture transmission system (APT) giving broadcasts of television pictures every $3\frac{1}{2}$ minutes. Relatively simple equipment on the ground could receive the pictures during the time the satellite was above the horizon at the receiving station (see Plate II). The APT system was in experimental use for only a few weeks on TIROS VIII and NIMBUS A but some remarkable results were obtained and the operational value of directly-received satellite pictures was demonstrated.

Infra-red scanning equipment has also been carried on some of the TIROS satellites and on NIMBUS A. The infra-red observations have been used extensively in research projects concerned with the heat balance of the earth and atmosphere. Furthermore night-time cloud photographs were obtained from NIMBUS A using high-resolution infra-red equipment (see Plate III).

The United States and the United Kingdom co-operated in the ARIEL satellite project. The ARIEL II satellite carried British equipment designed to obtain the vertical distribution of ozone in the atmosphere at each satellite sunrise and sunset.

The observational capabilities of satellites.—The composite nephanalyses produced by the United States Weather Bureau from the space-stabilized (or spin-stabilized) TIROS satellites have been based on up to 32 separate satellite pictures. A resolution down to about one mile is possible at the centre of a picture taken vertically downwards. The resolution is much poorer when the satellite, maintaining the direction of its axis of spin in space, takes a slant view of the earth. The coverage for one picture taken vertically is about 1200 kilometres square.

Since the experimental TIROS satellites were spin stabilized with the spin axis in the plane of the orbit, there were long periods of each orbit during which the cameras were not pointing towards the earth; this limits the usefulness of the nephanalyses.

The satellites in the operational satellite system (TOS) will also be spin stabilized but now with the spin axis normal to the plane of the orbit so that the satellite will behave like a 'rolling wheel' (see Plate IV). The cameras mounted on the 'rim' of the 'wheel' will be activated only when they are pointing towards the earth, thus giving maximum resolution for each picture and facilitating the addition of a grid to give latitude and longitude. The planned polar orbit will allow regular daily surveillance of the whole of the earth's surface. The main limitations of the operational system will be the reduction of ground illumination towards the winter pole and the delay in compiling composite nephanalyses.

The time factor in satellite data.—Pictures are generally not available in 'real time' i.e. at the time they are taken, because the data obtained are stored and later 'read out' at a time when the satellite can be commanded by one of the ground control stations in the United States. The process of compiling nephanalyses is a complex one which takes time. A composite picture is compiled from separate photographs and a grid is included to give latitude and longitude. The composite is then translated into a nephanalysis suitable for transmission by facsimile or teleprinter. The total delay in receiving a nephanalysis in the U.K. usually varies from about five to eight hours, occasionally much longer and rarely shorter.

Satellite data should be available within about three hours of observation in order to be of maximum use to a forecaster or in a computer programme. The satellite data can then be processed together with other data available at the most recent main synoptic hour.

The automatic picture transmission (APT).—The APT facility avoids some of the delay associated with nephanalyses. The forecaster has the advantage of receiving current or 'real time' data for a large surrounding area.

The coverage for each APT transmission, taking place every $3\frac{1}{2}$ minutes, will be about the same as for the individual pictures used in the composite nephanalyses and the resolution will similarly be about one mile. Any one ground station should be able to receive about three pictures during each orbit, and to follow three consecutive orbits. For a station in the British Isles this should, under the best conditions, give coverage roughly from the Denmark Strait to the eastern Mediterranean and from the Azores to the Barents Sea. The installation of APT receiving equipment on weather ships would considerably extend the observed area over the Atlantic if the satellite signal could be relayed to land receiving stations equipped with the appropriate facsimile recorders.

The basis of improvement in forecasting.—The improvement of forecasting services depends upon four interrelated factors:

- (i) an increase in the range, quantity and quality of observations;
- (ii) the reduction of the interval between the time of an observation and its availability to the forecaster or computer;
- (iii) the development of specialized services to meet increasing requirements; and
- (iv) advances in meteorological knowledge leading to improvements in forecasting techniques.

These four factors may be used as a basis for assessing the effect of satellite data on forecasting techniques and services.

The uses of meteorological satellites in forecasting.—

APT pictures.—The most useful direct contribution of an operational satellite system to forecasting in the immediate future is likely to be provided by APT pictures which have the considerable advantage of providing, within an analysis centre, current observations over a wide surrounding area. On most occasions APT pictures should provide valuable information to supplement existing forecasting services for aviation, particularly if accumulated experience and research allows the forecaster to extract 'hidden' data related to such factors as turbulence or icing. These advantages are, however, offset to some extent by the limitation of APT coverage to two or three consecutive orbits near noon from one satellite and by the difficulty of interpreting satellite pictures.

Regional forecasting.—Some improvement in short-range forecasting accuracy should follow the routine use of APT data. For example, in regional forecasting for the British Isles it would be very useful, in an easterly situation, to have some idea of the distribution of cloud over the North Sea, or in a westerly to know how cloud is organized over the Irish Sea, the English Channel and the western and north-western approaches, and what effect high ground is having under particular circumstances. With increased experience and research into the interpretation of APT pictures it may prove possible to establish some

relation between the intensity of rainfall and cloud patterns or cloud-top reflectivities, provided that the APT receiving equipment is capable of reproducing the tonal range of the original satellite signal.

Area forecasts.—For forecasting over much wider areas, the nephanalyses produced by the United States Weather Bureau in Washington, and given international distribution, will take on a greater importance with an operational satellite system than they have had in the experimental phase because global data will be available on a routine basis. The present form of nephanalysis, as received by facsimile, is probably the best method of giving the data a wide distribution, although the National Weather Satellite Center of the U.S. Weather Bureau welcomes suggestions for improvements from users. Each nephanalysis contains a wealth of data, identifying cirriform, cumuliform and stratiform cloud, jet cores (by the shadow of the cirrus edge on lower cloud), and the character and organization of cloud systems on every scale from the frontal cloud of major depressions down to the cloud streets of the sub-tropical Trades or polar outbreaks.

Analyses.—Experience in relating nephanalyses, or APT pictures, to conventional analyses has already shown that the distribution of cloud is occasionally different from that suggested by analyses based on the coarse grid of observations on surface and upper air charts. This implies that the full potential of satellite observations cannot be realized in existing forecasting techniques. Even so, any analyst to whom satellite data are available should give the information full consideration even if the data arrive late and can only be used to revise analyses on which forecasts have already been issued. Over ocean areas the extrapolation of cloud systems observed by the satellite may be important to future forecast issues, and should help to make widely-separated ship observations more meaningful.

Air survey.—A direct application of APT in the improvement of services to aviation is in air survey in remote areas. Aircraft, crews and ground equipment may be inactive for long periods waiting until clear skies permit the completion of an air survey. If the area is remote the available observations may be few and far between and forecasting clear skies can be extremely difficult, particularly in or near the intertropical convergence zone where the terrain is usually such that air survey is the only practical form of mapping or prospecting. The capital cost of APT receiving equipment is likely to be more than recovered under these circumstances.

Snow cover.—Some remarkable satellite pictures of snow and ice cover have already been obtained and it might be expected that an operational satellite system, giving regular snow cover observations within the limits set by cloudiness, would provide some means of assessing river flood levels, hydroelectric resources and reservoir inflow.

Ice limits.—The boundary between sea ice and open water is likely to be a region of increased cloudiness but there should be a sufficient number of occasions of clear skies in such areas for routine satellite observations to provide information on ice-limit changes which might be of importance for climatology and long-range forecasting. Ice-limit observations would, in any case, be of direct use in navigation at sea.

Satellite data and the development of forecasting techniques.—Satellite pictures of cloud systems have shown many unusual features such as clear areas where dry

air has penetrated right through the frontal zones in occluding depressions, apparent vortices in the distribution of convective cloud in polar air which are closely related to the thermal wind field, and cloud systems only loosely associated with conventionally positioned fronts (Sawyer²). The significance of an operational satellite system is that conventional surface and upper air observations will be reinforced by satellite observations with a resolution down to about a mile over land and sea alike. Satellite observations of cloud and its organization will go a long way to completing a full description of the actual behaviour of the atmosphere when added to the observations of widely-spaced radiosonde ascents and the limited information which can be conveyed in the coded versions of surface observations. Perhaps the real importance of satellite data to the development of forecasting techniques lies in the observations of cloud organization.

To use satellite data to confirm or amend conventional analyses is of limited short-term use but one which should serve to convince the synoptic meteorologist that the observations provided by operational satellite systems are likely to lead to new concepts of behaviour of the atmosphere and these, carried forward on computer techniques, may eventually lead to major advances in the accuracy and applications of forecasting services.

Meteorological research using TIROS data.—The data obtained from a TIROS satellite are basically of two types. The photographs are obtained by the projection of the whole of the field of view of the optical system on to a sensitive surface whilst the radiation measurements are made by scanning the field in small sections. Research using the data has, in general, continued to follow such a division determined more by the availability and quality of the measurements rather than by the instrumentation or wavelength.

Although less than five years has elapsed since the launch of TIROS 1 the quantity of research publications concerned with satellite data is enormous as indeed is the diversity of topics involved. Consequently only a selection of this research can be presented here. For a fuller description of some of these topics we refer you to other writers, for example Hanson.³

Photographs.—Even on the first photographs received in April 1960 it was obvious that in the cloud patterns there were significant features which were not evident from conventional surface observations. Investigations relating to the interpretation of cloud patterns have been reported by Erickson and Hubert⁴ and Conover.⁵ Both of these papers attempt to identify clouds observed in satellite photographs in terms of classifications based on ground observations. They show that provided the clouds are large enough to be resolved by the optical system and dense enough to reflect sufficient light into the field of view of the camera it is indeed possible to identify cumulus, stratocumulus and so on; for cloud patterns however, only a few crude classifications are possible from conventional surface observations. In this respect satellite photographs have been quite an eye-opener showing cloud organization on scales from 10 miles—the dimensions of maritime convection cells (see for example Krueger and Fritz⁶)—up to 1000 miles—the dimensions of a middle latitude depression (see for example Boucher and Newcomb⁷).

The orbital inclination of the earlier TIROS satellites was only 48° so that relatively few photographs were obtained in the middle and high-latitude regions. The coverage at the equator however was excellent and a considerable

amount of research was concerned with the cloud types and structures associated with meteorological phenomena found in these regions. In particular, photographs have shown that there have been facets of the structure of the hurricane (Fett⁸) which were not suspected from conventional surface observations. For example, there seem to be intense squall lines which completely ring the hurricane and are separated from it by a well-defined clear area. Furthermore the origin of such storms has—certainly in two instances—been shown to be considerably further east than had been previously suspected. Fritz⁹ in analysing the origins of hurricanes ANNA and DEBBIE found that they could be traced to disturbances of the easterly flow over central Africa.

Most research using TIROS photographs has been concerned with case studies of individual phenomena, for example a sharp-edged bright cloud which produced a severe storm over central U.S.A. (Whitney¹⁰) or a developing depression (Timchalk and Hubert¹¹). Researches such as these have tended to show the distance over which the particular meteorological disturbance exerts an influence. For example the bright clouds described by Whitney which were associated with distinctly separate areas of thundery activity were of the order of 100 miles across, whilst developing depressions exerted an influence over an area with linear dimensions of more than 1000 miles. This sort of research with limited objectives has been very profitable if only to show that the organization of clouds in association with meteorological phenomena does not usually conform with theories based entirely on surface observations.

The operational value of satellite cloud photographs will be increased if they can provide quantitative data for use in numerical weather prediction. Unfortunately there does not seem to be a one to one correlation between cloudy areas and any of the parameters at present used numerically (even the positioning of the centres of cloudiness may differ by 100 or 200 miles from the position of the surface depression, see for example Boucher and Newcomb⁷). Investigations relating to this problem have therefore been confined to subjective trial and error techniques. Broderick¹² obtained the expected correlation between extensive cloudiness as observed from the TIROS photographs and the advection of cyclonic vorticity at 500 mb. The correlation was too weak to be of practical use and although it could be improved when it included only those cases where the advection term was greater than a certain value it was still not good enough to be of use objectively. However he concluded that the correlation was usable if the analysis also included other features of the synoptic situation determining the structure of the cloud sheet. To our knowledge the only published attempt to introduce cloud analyses from TIROS photographs into numerical forecasting has been that of Ruzecki.¹³ In this report an example was selected of a contour analysis over the Pacific from which the computed vertical motions at 500 mb (proportional to the vorticity advection at this level) did not seem to agree with the cloud distributions as shown by a TIROS photograph of the same area. Ruzecki assumed that thick middle-level clouds would be found in the areas of strong, positive vorticity advection and used an iterative technique to adjust the stream function and the field of vorticity advection to agree with both the TIROS photograph and the conventional upper air observations. The redefined initial data field was then fed to the computer and a routine numerical forecast obtained. There is little doubt that an improvement was made to the forecast 500 mb contour field. This is only one example, but it is understood that more

cases are being re-analysed in a similar fashion by a group at the Satellite Laboratory of the U.S. Weather Bureau. This is but a small beginning to a project which may be vital to the future of meteorological information from satellites—and perhaps for numerical forecasting too.

Radiation data.—The satellites TIROS II, III, IV and VII each carried a five-channel radiometer capable of measuring radiances in five different spectral intervals. A full description of the instrument is given elsewhere, for example Hanel and Wark.¹⁴ Briefly, each channel of the radiometer consists of a thermal detector which receives radiation through a filter determining the spectral interval, and reception is arranged alternately from two directions 180° apart. The output of the detector is thus an alternating voltage whose amplitude is proportional to the difference in radiance from the two directions. When one of these is directed towards the earth the other points towards space where the radiance is effectively zero, so that the output depends on the amount of incoming radiation from the earth and the atmosphere.

During the four years that have elapsed since the launch of TIROS II, the first satellite to carry a radiometer, an ever-increasing volume of literature has appeared dealing with the accuracy of the observations and the application to meteorological investigations. No attempt will be made at a summary here; rather we will select various aspects of these researches which appear to us to have produced or to be likely to produce significant meteorological information. First, however, a word should be said about the performance of the instrument itself. There is little doubt that the instrument on each occasion deteriorated rapidly after being launched. It is not known for certain what causes this degradation—possibly a change of reflectivity of the mirrors—but since it exists and can be calibrated only empirically we must treat with some suspicion any deductions made from the absolute values of the radiances observed. This should be borne in mind in the discussion which follows.

Channel II of the radiometer measures radiances in the spectral interval 8 to 12 microns. This is loosely termed the atmospheric 'window', by which we mean that at these wavelengths there is no absorption by atmospheric constituents. Thus in cloud-free areas the radiation in this interval measured at the satellite comes entirely from the ground and could give an estimate of the surface temperature. For an extensive cloud sheet the radiation would rise from the cloud itself enabling an estimate of cloud-top temperature. Unfortunately the 'window' is not perfect, there being absorption by ozone and slight absorption by water vapour too, so that any temperatures deduced directly would be in error. A correction therefore has to be applied for the distribution of these gases and also for the length of path between the earth and the satellite. This correction has been determined empirically by Wark, Yamamoto and Lienesch¹⁵ and reduces the measured radiances to surface temperatures. Naturally to obtain accurate estimates of surface or cloud temperatures one should know the distribution of ozone and water vapour in the path. Although the former may be obtained with sufficient accuracy from published data of ozone measurements the variability of water vapour in the troposphere could lead to errors of more than 5°C in surface temperatures.

One of the earliest uses of the Channel II data was described by Fritz and Winston¹⁶ who plotted the radiances, reduced to effective black-body temperatures, on a synoptic chart which also showed frontal boundaries and cloud cover. As we might expect, the high and low temperatures corresponded to clear and

cloudy areas respectively, with the lower temperatures agreeing with the denser and higher cloud sheets. Furthermore, using representative temperature soundings it was possible to put heights to the cloud tops. This technique was applied to other examples by Rao and Winston¹⁷ who also pointed out ambiguities which might arise if one assumed that all low temperatures occurred with high cloud. In their examples snow-covered areas had lower temperatures than cloudy regions nearby. They also observed that the decrease in radiance apparently caused by particulate matter near the tropopause gave erroneously low values for surface temperature. Their paper clearly emphasizes the fact that the radiation data of Channel II possess anomalies only partially explained by the presence of ozone and water vapour. However even this data can be used to locate cloudiness, to show variations in the cloud-top heights and to portray variations of surface temperature. It should be noted here that an optical system using a narrow band within the window region was used on NIMBUS A to observe cloud cover at night.

Channel IV of the satellite radiometer measures radiances within the spectral interval 8 to 30 microns and was included because this measurement represents a substantial fraction of the total intensity of terrestrial radiation. To obtain the outgoing flux, that is the radiation leaving unit area of the atmosphere, it is necessary to integrate the intensity over a hemisphere. This requires a knowledge of the angular variation of the intensity which in turn depends on the distribution of absorbing gases within the beam. Wark, Yamamoto and Lienesch¹⁵ used more than 100 model atmospheres with various temperature and humidity combinations to determine this angular variation for various types of atmosphere, and have presented some examples of outgoing flux from a series of TIROS II observations.

One of the first analyses of Channel IV data has been reported by Winston and Rao¹⁸ using TIROS II data for about 25 days in the winter of 1960. They constructed a composite map of outgoing long-wave radiation for the northern hemisphere. They showed that the average latitudinal distribution so obtained agreed tolerably well with the computations of other workers and that small-scale fluctuations about this average could in some cases be associated with changes in the zonal flow. But perhaps their most important conclusion was that there was a correlation between temporal variations of long-wave radiation and corresponding variations of available potential energy, a parameter which is closely linked with the general circulation of the atmosphere.

Before concluding this section special mention must be made of the radiometer on TIROS VII. The radiometers on earlier satellites suffered considerably from rapid degradation preventing any long-term radiation studies. That carried on TIROS VII had also experienced degradation but at a much lower rate and more than a year's radiation data have been obtained from it. Bandeen, Halev and Strange¹⁹ using a year's data from this satellite have derived a radiation climatology for the earth between latitude 63°N and 63°S. They calculated the latitudinal variation of (i) the annual (June 1963 to May 1964) long-wave heat loss derived from the 8 to 12 micron channel and (ii) the planetary albedo from the 0.55 to 0.75 micron channel. Further, the seasonal variation of these quantities could be indicated. Perhaps the most interesting aspect of the analyses however is the interpretation of the 14.8 to 15.5 micron channel. Within these wavelengths carbon dioxide, which is uniformly distri-

buted in the atmosphere, absorbs strongly all the radiation coming from the earth and then re-radiates an amount determined by its own temperature. The distribution of the gas in the stratosphere is such that only a small amount of energy originating in the troposphere reaches the satellite so that the measured radiance is indicative of the temperature of the stratosphere. Bandeen and his co-authors show the distribution of the stratospheric temperatures obtained during four weekly periods from June 1963 to March 1964. A surprising feature of these charts is the persistence of a warm stratosphere over the North Pacific region from the 15 to the 22 January 1964, displacing the cold, stratospheric vortex which might be expected around the Pole. The satellite measurements also indicated that in the second half of January 1964 there had been a stratospheric warming of more than 15°C with its centre near Asia Minor. These observations have been amply supported by STRATWARM alerts issued by Professor Scherhag at Berlin and to a lesser extent by observations from the Meteorological Office Skua rocket fired from South Uist at about the same time (Almond, Farmer and Frith²⁰).

Conclusions.—In the preceding sections we have reviewed the implications of meteorological satellites for research and for forecasting services. Television pictures and infra-red observations from the experimental TIROS and NIMBUS satellites have provided data for many promising and active lines of research and practical experience in incorporating satellite data into conventional analyses. Some uses of satellite data will be of immediate value to forecasting services but already there are indications that new approaches to many hitherto intractable problems in meteorology may be possible through satellite observations, and advances in fundamental research over a wide range of problems should be possible when routine satellite data are available. For operational use the satellite observations must ultimately be able to provide data suitable for input to a computer and already a promising start has been made in this direction.

Among practising forecasters the availability of meteorological information from satellites has probably evoked more defensive pessimism than enthusiastic optimism. The actual organization of cloud systems is far more complex than the rough approximations and simplifications of existing analytical and forecasting techniques have led us to expect; there are still problems in getting the information to the forecaster in time for it to be used, and observations are not the sole arbiter in forecasting accuracy. Accumulation of satellite data should challenge our existing concepts and techniques and methods of presentation of forecast data.

Progress in meteorology, both in research and its applications to forecasting, is likely to accelerate rapidly in the next decade and data from meteorological satellites operating as part of World Weather Watch will provide much of the observational support for the advance. The use of data from the operational meteorological satellite system will play an increasingly important part in the international development of meteorological services.

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THE DIURNAL MARCH AND INTERDIURNAL VARIABILITY OF THE DURATION OF SUNSHINE AT ATHENS

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Summary.—Hourly values of the Athens sunshine data for the period 1959–63 are analysed. The sunshine at Athens does not show a remarkable diurnal variation for all months and seasons or the year as a whole. However, because of the diurnal variation of cloudiness, a preference is revealed for a maximum in the morning hours in spring and summer and in the noon hours in the corresponding months in winter and autumn.

The interdiurnal variability of sunshine, that is the difference between the duration of sunshine on one day and that on the next, shows a regular annual course—maximum in winter and minimum in summer. This occurs for interdiurnal rises and falls and also for variability irrespective of sign and is due to the interdiurnal cloud variation.

Introduction.—It is well known that the duration of sunshine constitutes one of the most important elements of climatology and is often used as a substitute to gauge the solar climate of a place. The sunshine is usually expressed as the number of hours per month or per year and also as a percentage of the possible sunshine for a particular place.

With regard to the Athens area, such a tabulation exists dating back to 1896. For the period 1959–63, hourly values expressed as a percentage of the possible sunshine are also available. These values are for hours when sunshine could

occur for the whole hour (60 minutes) and so, for example, 30 minutes of sunshine in an hour represents 50 per cent of the possible. It seemed worthwhile analysing the data for 1959-63 in order to study the diurnal march and inter-diurnal variability of the duration of sunshine. For convenience only the hours from 0800 to 1700 (Local Apparent Time, LAT) are discussed, these being the times between which the sun is above the horizon in all months of the year.

The records discussed were made with a Campbell-Stokes sunshine recorder on the hill of the National Observatory of Athens ($37^{\circ}58'N$, $23^{\circ}43'E$, and 107 metres above sea level).

Diurnal march of sunshine.—The diurnal march of sunshine is obviously governed by the cloudiness and also by the occurrence of fog and dust. However, because of the effects of the different kinds of clouds, an accurate relationship cannot exist between recorded sunshine and cloudiness. The sun may shine even if the sky is cloudy or it may be obscured even if the sky is not completely overcast.

Table I presents, within the hours 0800 to 1700 LAT, the average hourly values of sunshine at Athens expressed as a percentage of the possible for each hour during each month and season and for the year as a whole.

TABLE I—AVERAGE DIURNAL MARCH OF SUNSHINE AT ATHENS, (1959-63)

	Local Apparent Time								
	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
	percentage of possible								
January	47	55	57	54	57	57	53	48	23
February	51	57	62	66	64	61	61	55	36
March	54	60	62	61	60	60	57	57	42
April	77	78	75	74	76	74	69	69	64
May	85	86	85	82	78	75	75	77	74
June	95	94	93	87	85	89	85	83	83
July	97	96	96	97	94	93	94	95	95
August	99	99	98	98	98	98	97	96	95
September	89	92	90	90	88	88	88	89	81
October	66	72	71	72	73	69	67	61	44
November	57	66	72	77	76	73	66	56	25
December	42	54	55	56	53	51	44	36	12
Winter	47	55	58	59	58	56	53	46	24
Spring	73	75	74	72	71	70	67	68	60
Summer	97	96	96	94	92	93	92	91	91
Autumn	71	77	78	80	79	77	74	69	50
Year	72	76	76	76	75	74	71	68	56

As it appears from this table, the sunshine at Athens does not show a regular diurnal course for all months studied. Nevertheless a tendency is revealed towards a maximum in the morning hours of the spring and summer months, while for the winter and autumn months the same applies for the noon hours. This tendency is clearer if the seasons are considered.

The cause of this behaviour of the diurnal march of sunshine must be sought mainly in the diurnal march of cloudiness. Indeed, especially in winter, the maximum of cloudiness occurs during the early morning hours when stratiform clouds are most frequent.¹ In summer, on the other hand, convection increases the cloudiness during the early afternoon hours. If the year as a whole is considered, the diurnal course of sunshine at Athens presents the maximum values (76 per cent) in the three forenoon hours.

Concerning the minimum values of sunshine and therefore its diurnal range, it must be noted that the Campbell-Stokes recorder is not a perfect instrument. As a result the minimum values are rather doubtful.

In general, although the fluctuation of the diurnal march of Athens sunshine is not remarkable, Table I gives a useful picture of the sunshine duration for each hour (LAT) at Athens.

Interdiurnal variability of the duration of sunshine.—As is well known,^{2,3} among the irregular fluctuations of climatic elements are the changes from one day to another, which indicate the variability of the weather. These variations from one day to the next are known as interdiurnal variability and besides the variability irrespective of sign, the rises and falls of the element under consideration can be studied separately (see Table II).

TABLE II—INTERDIURNAL VARIABILITY OF SUNSHINE HOURS AT ATHENS, 1959–63

	Average change irrespective of sign <i>hours</i>	Average rises (<i>R</i>) <i>hours</i>	Average falls (<i>F</i>) <i>hours</i>	Ratio <i>R/F</i>	Rises <i>percentage</i>	Falls <i>frequencies</i>	No change	Absolute maximum values Rises <i>hours</i>	Falls <i>hours</i>
Jan.	3.1	3.2	3.2	1.00	49	48	3	8.7	8.9
Feb.	3.3	3.2	3.7	0.86	50	47	3	9.5	9.1
Mar.	3.2	3.5	3.3	1.06	47	46	7	10.1	8.6
Apr.	2.7	2.7	2.6	1.04	47	53	0	11.8	8.0
May	2.6	2.8	2.7	1.04	48	48	4	10.8	10.9
June	1.9	1.9	2.3	0.83	53	42	5	8.2	10.5
July	0.9	0.9	0.9	1.00	47	46	7	5.8	5.9
Aug.	0.7	0.7	0.8	0.88	40	50	10	6.0	6.9
Sept.	1.4	1.7	1.3	1.31	39	56	5	9.1	10.0
Oct.	2.6	2.6	2.8	0.93	50	48	2	8.8	9.2
Nov.	2.6	2.7	2.6	1.04	47	52	1	9.0	7.9
Dec.	3.1	3.3	3.3	1.00	48	46	6	8.7	8.8
Winter	3.2	3.2	3.4	0.94	49	47	4	9.5	9.1
Spring	2.8	3.0	2.9	1.03	47	49	4	11.8	10.9
Summer	1.2	1.2	1.3	0.92	47	46	7	8.2	10.5
Autumn	2.2	2.3	2.2	1.05	45	52	3	9.1	10.0
Year	2.3	2.4	2.4	1.00	47	49	4	11.8	10.9

Under the control of the day-length alone, each day should obviously have a greater duration of sunshine than the preceding day during the interval between minimum and maximum day-length, and a smaller one between maximum and minimum day-length (December and June solstice respectively). However, besides the day-length, the cloudiness and also fog and dust in the air produce irregular interdiurnal changes.

The first column of Table II shows that there exists a strongly-marked regular annual course of the interdiurnal variability irrespective of sign. The maximum (3.3 hours) appears in February and there is a marked minimum (0.7 hours) in August. Hence the annual range is 2.6 hours.

Almost the same picture appears in the annual course of the rises and falls (second and third columns of Table II) with high values in winter and the first month of spring and low values in summer and the first month of autumn. The annual ranges amount to 2.8 and 2.9 hours for rises and falls respectively and the average monthly values of rises and falls are very closely correlated, the correlation coefficient being $+0.97$ with a probable error of ± 0.01 .

The behaviour of the annual course of the interdiurnal variability of sunshine hours must be attributed to the cloud variation which is small in summer and great in winter. Especially during the cold period there are in the Athens area frequent alternations of cyclonic and anticyclonic conditions which create dense cloudiness and clear weather respectively.

The ratios of monthly rises and falls are also given in Table II. These ratios have rather small variations in the course of the year and are ≥ 1.00 in the majority of cases.

Attention may be directed also to the last five columns of Table II which give the percentage frequencies of rises, falls and occasions of no change (i.e. a difference of 0.0 hours), and also absolute maximum values of rises and falls. From this picture it appears that the greatest contrasts between the frequencies of rises and falls occur in the first month of both summer and autumn (53 as against 42 in June and 39 as against 56 in September). The steady conditions, on the other hand, present a minimum value (0 per cent) in April and a maximum (10 per cent) in August. Concerning the absolute maximum values of rises (11.8 hours in April) and falls (10.9 hours in May) it is to be noted that both occur in the spring.

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551.511.3:551.521.1:551.524.32

THE DISTRIBUTION AND ANNUAL CYCLE OF LOCAL HEATING RATE THROUGHOUT THE TROPOSPHERE IN THE NORTHERN HEMISPHERE

By G. B. TUCKER

Introduction.—During the past few years several attempts to represent the spatial distribution of sources and sinks of heat over the northern hemisphere have been published.^{1,2} The order of magnitude of this heating and cooling is 10^{-3} g cal $\text{cm}^{-2} \text{sec}^{-1}$, but the observed local rate of change of total heat content of the atmosphere is only of the order of 10^{-4} g cal $\text{cm}^{-2} \text{sec}^{-1}$. This is because the local temperature change is the result of a small residue between the heat sources (and sinks) and the redistributive effects of horizontal and vertical motion in the atmosphere. This relation can be represented by the formula

$$\bar{R} + \bar{L} + \bar{H} = -\frac{c_p}{g} \int_{\bar{p}_s}^0 \frac{\partial \bar{T}}{\partial t} d\bar{p} - \frac{c_p}{g} \int_{\bar{p}_s}^0 \left(\bar{\mathbf{V}} \cdot \nabla \bar{T} + \frac{\bar{T}}{\bar{\theta}} \bar{\omega} \frac{\partial \bar{\theta}}{\partial \bar{p}} \right) d\bar{p}. \quad \dots (1)$$

The three terms on the left-hand side represent the rate of heating in a vertical column of atmosphere of unit cross-section due to net radiation (\bar{R}), liberation of latent heat (\bar{L}), and the rate of gain of sensible heat by exchange with the earth's surface (\bar{H}). The first term on the right-hand side represents the heat storage or local rate of change of total heat content of the column; c_p is the specific heat of air at constant pressure; g , acceleration of gravity; T temperature; t time; p pressure; p_s representing the pressure at the earth's surface. The remaining terms on the right-hand side represent the redistributive effects of horizontal motion and of vertical motion; \mathbf{V} is the vector representing horizontal velocity; $\omega \equiv dp/dt$ vertical motion; θ potential temperature. Horizontal bars represent mean values in time—in this case one month.

Clapp¹ has discussed the difficulties of independently estimating both sides of this equation for a normal winter. Shaw³ has dealt in detail with the diffi-

culties involved in estimating the redistributive terms on a monthly basis. The object of this paper is to represent the distribution of the heat storage term over the northern hemisphere throughout the year, i.e. to represent the geographical distribution of the annual variation of the rate of change of total heat content of the troposphere.

Method.—The average total heat content from the surface to 200 mb was estimated for each month for five years at 78 stations distributed over the northern hemisphere (Figure 1). The years chosen were 1955 to 1959 inclusive, and CLIMAT temperature data at the surface, 850, 700, 500, 300 and 200 mb levels were used. Five-year average values for each month of the year were

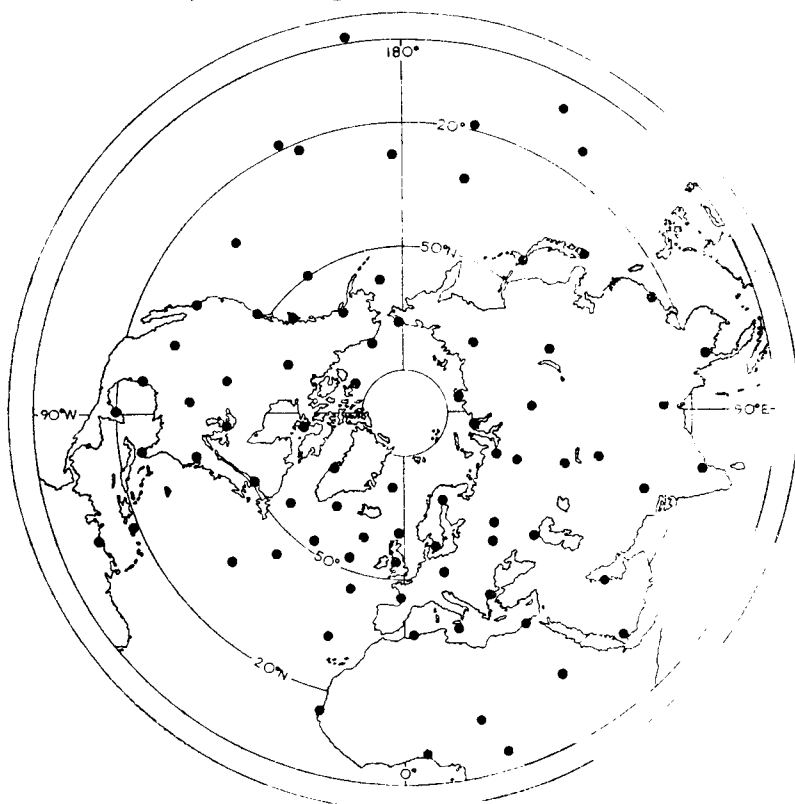


FIGURE 1—KEY MAP OF STATIONS USED

next obtained. The local rate of change of total heat content between successive months was then estimated using the following expression

$$-\frac{c_p}{g} \int_{\bar{p}_s}^{200} \frac{\partial \bar{T}}{\partial t} d\bar{p} = - \left[\frac{c_p}{g \Delta t} \int_{\bar{p}_s}^{200} \bar{T} d\bar{p} \right]_{m+1} + \left[\frac{c_p}{g \Delta t} \int_{\bar{p}_s}^{200} \bar{T} d\bar{p} \right]_m$$

where the subscripts $m, m+1$ refer to consecutive months and Δt is the time interval between the middle of one month and the next.

The root mean square deviation of individual monthly values of total heat content about the 5-year mean obviously varies with place and time of year; for the 78×12 station-months examined the average value was approximately $400 \text{ g cal cm}^{-2}$. Corresponding to this value a reasonable estimate of the standard error of the charts of local rate of change of total heat content can be shown to be approximately $0.9 \times 10^{-4} \text{ g cal cm}^{-2} \text{ sec}^{-1}$.

Results.—Charts of the normal local rate of change of total heat between successive months throughout the year are given in Figures 2–13.

Before discussing individual charts it should be noted that values south of 20°N generally have a magnitude of less than $0.5 \times 10^{-4} \text{ g cal cm}^{-2} \text{ sec}^{-1}$ and are thus comparable with the standard error. Also the distribution of stations in these low latitudes is very sparse. Discussion will therefore be confined mainly to middle and upper latitudes. In the remainder of this article the terms ‘warming’ or ‘cooling’ will refer to increasing or decreasing total heat content in the troposphere, i.e. to areas of rising temperature or falling temperature, and not to the rate at which heat is supplied or abstracted locally.

At the commencement of the year (Figure 2) some warming is already beginning to take place in high latitudes in the form of a three-lobe pattern with centres over Alaska, south of Iceland and to a lesser extent over Siberia. Between about 20°N and 50°N is a broad area of cooling with high values over the central North Atlantic and over Japan. The juxtaposition of positive and negative centres in the North Atlantic region at this time of year is consistent with the strongest thickness gradients and maximum intensity zonal winds occurring in this region in late January and early February (Willett⁴). A general warming appears to occur in very low latitudes. The high-latitude warming persists in late winter (Figure 3), but there has been a shift in the position of the three centres. The main change from the previous chart is the absence of any well-defined zone of cooling in middle latitudes.

The beginning of spring (Figure 4) is marked by an extension of the warming areas with a maximum centred over north-central Canada. The earlier three-lobe pattern of warming (Figure 2) is somewhat compensated by slight cooling in these areas at this time. Figures 5 and 6 show the ‘spring warming’ well under way, an increase in total heat content being experienced by nearly the whole hemisphere.

Figure 7 shows the ‘spring warming’ continuing well into June with the maximum centred near the pole. A feature of early summer (Figure 8) is that the local heating area is a maximum in a zone whose average latitude is about 50°N while a zone of cooling has extended northwards to an average latitude of 25°N . Towards the end of summer (Figure 9) cooling appears over much of the chart particularly in the western hemisphere. Maximum cooling at this time is centred close to the pole.

At the beginning of autumn (Figure 10) a three-lobe pattern of cooling is a feature of high latitudes, the centres of cooling occurring approximately mid-way between the centres of warming in winter (Figure 2). In late autumn (Figure 11) cooling continues over most of the middle and upper latitudes with the centre of maximum cooling near the pole.

Pronounced asymmetry in the pattern of cooling occurs in early winter (Figure 12) with a region of intense cooling centred over western Canada and to a lesser degree over Japan, and slight warming occurring over Scandinavia (this latter region has values of the same size as the standard error and thus the warming may be a feature merely of the five years chosen). In midwinter (Figure 13) cooling over Japan continues while a pronounced area of cooling is situated over the north-east Atlantic.

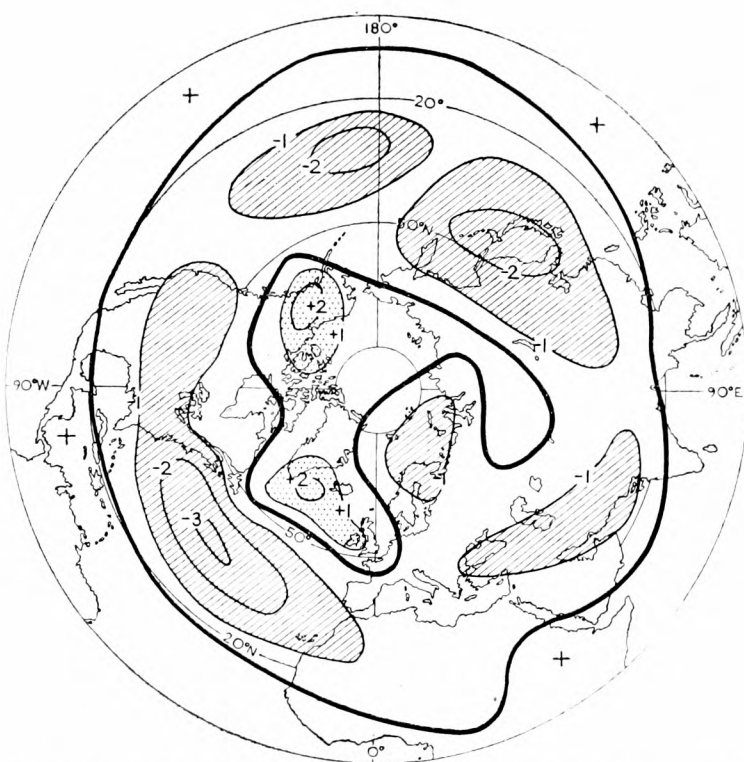


FIGURE 2—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, DECEMBER/JANUARY
Unit: $10^{-4} \text{g cal cm}^{-2} \text{s}^{-1}$

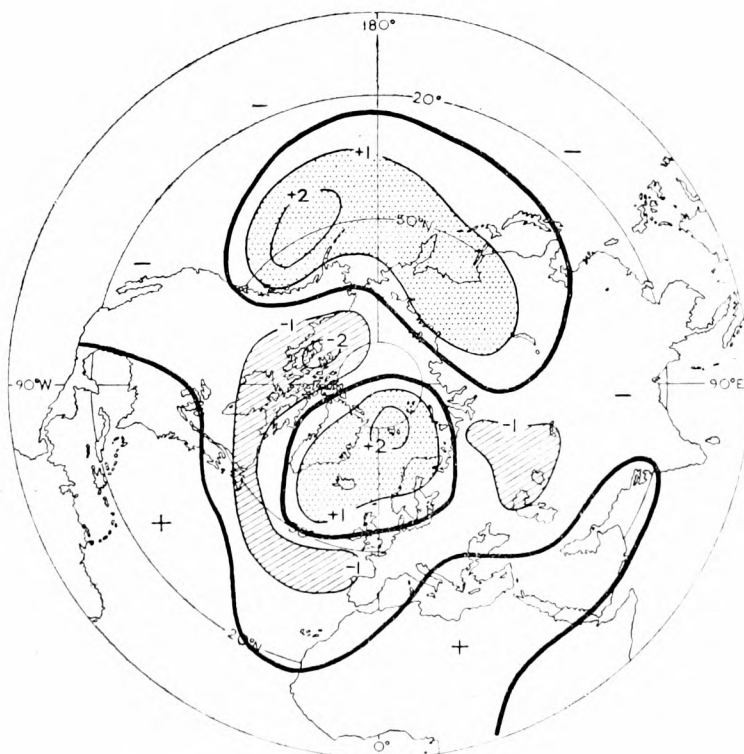
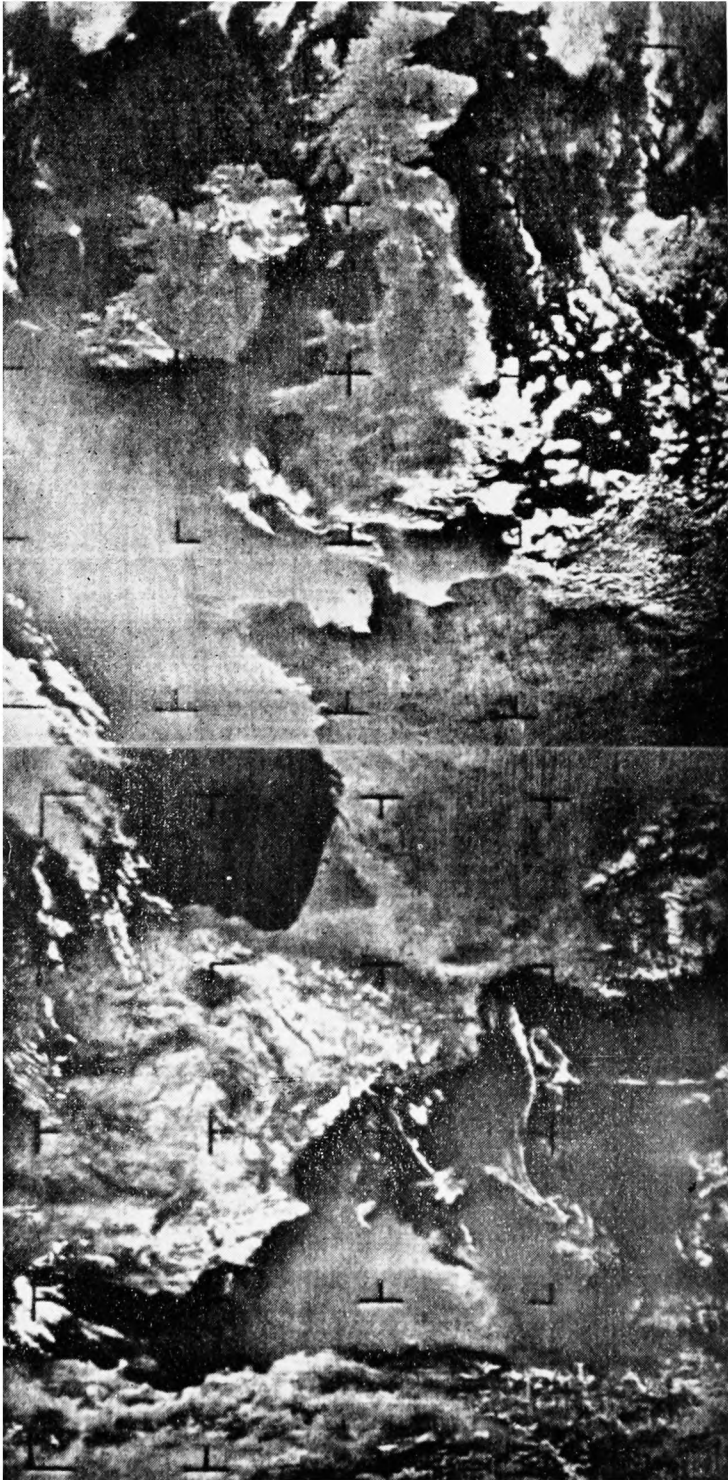


FIGURE 3—JANUARY/FEBRUARY



By courtesy of NASA

PLATE I—DOUBLE VORTEX OVER NORTH ATLANTIC OCEAN
Photograph by TIROS IX, orbit 0101 on 30 January 1965 (see page 193).

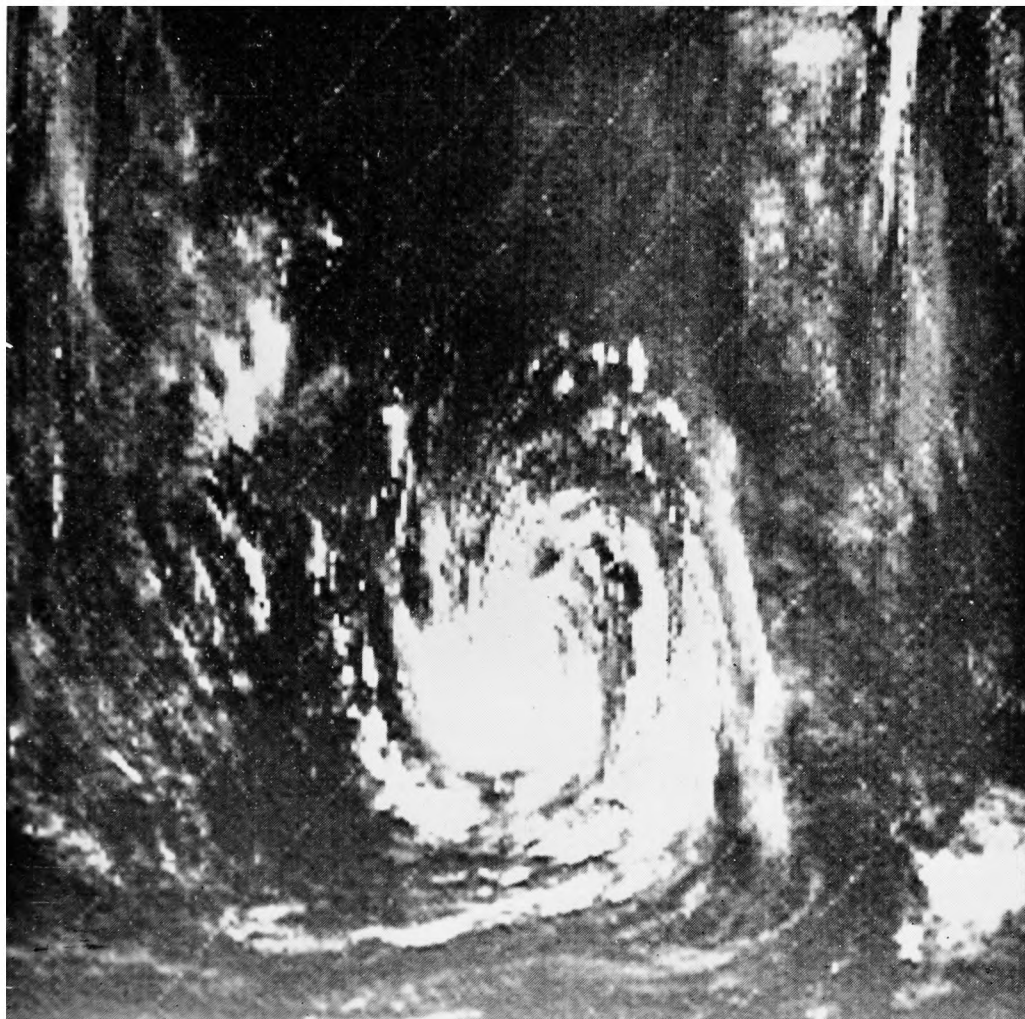


By courtesy of U.S. Weather Bureau

PLATE II—AUTOMATIC PICTURE TRANSMISSION RECEIVED AT LANNION, FRANCE

Photograph by NIMBUS A on ~~2 September~~ 1964 (see page 194).

31 AUGUST



By courtesy of NASA

PLATE III—HIGH RESOLUTION INFRA-RED PHOTOGRAPH OF HURRICANE ETHEL
Photograph by NIMBUS A on 10 September 1964 (see page 194).

TOS SYSTEM

ORBIT

750 n. miles alt. 12.75 orbits/day
Sun Synchronous 113.5 min/orbit
(Crosses equator same local time each orbit)

SATELLITE

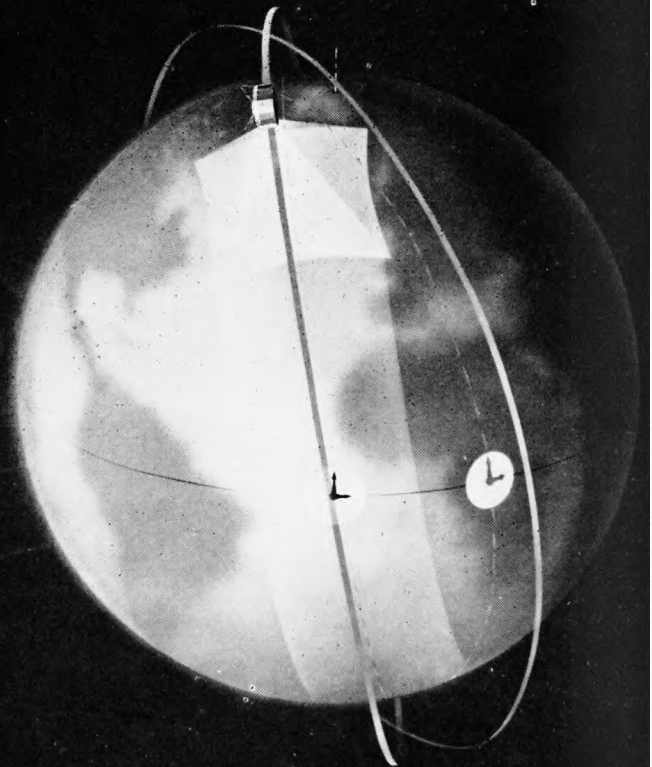
TIROS "wheel"
Cameras on "rim"
Spin axis perpendicular to
orbit plane

PICTURES

Daily Global Coverage through CDA stations] Stored data
Limited area coverage local readout	
Earth oriented pictures] APT

INFRARED

Night time cloud distribution
&
Heat balance data



By courtesy of U.S. Weather Bureau

PLATE IV—TIROS OPERATIONAL SATELLITE SYSTEM

See page 194.

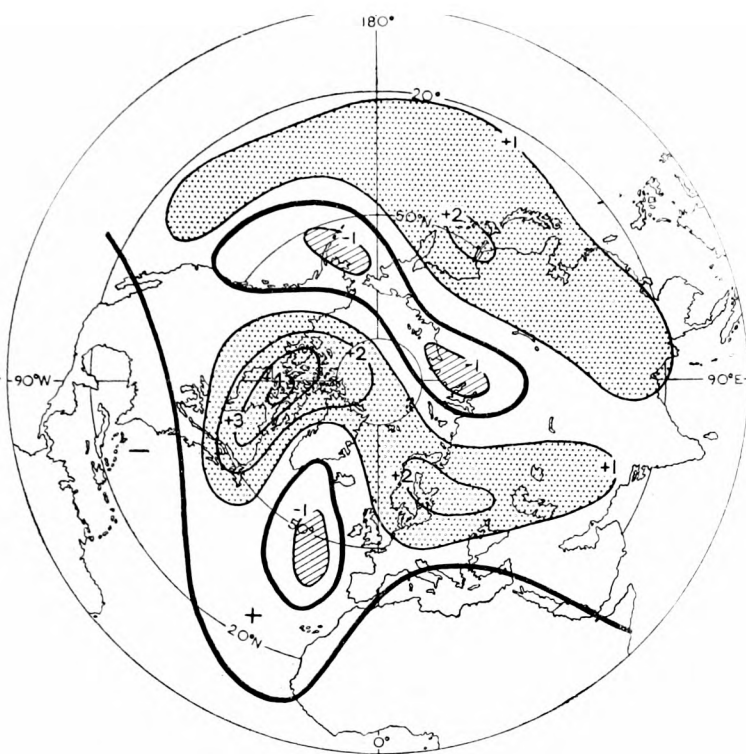


FIGURE 4—FEBRUARY/MARCH

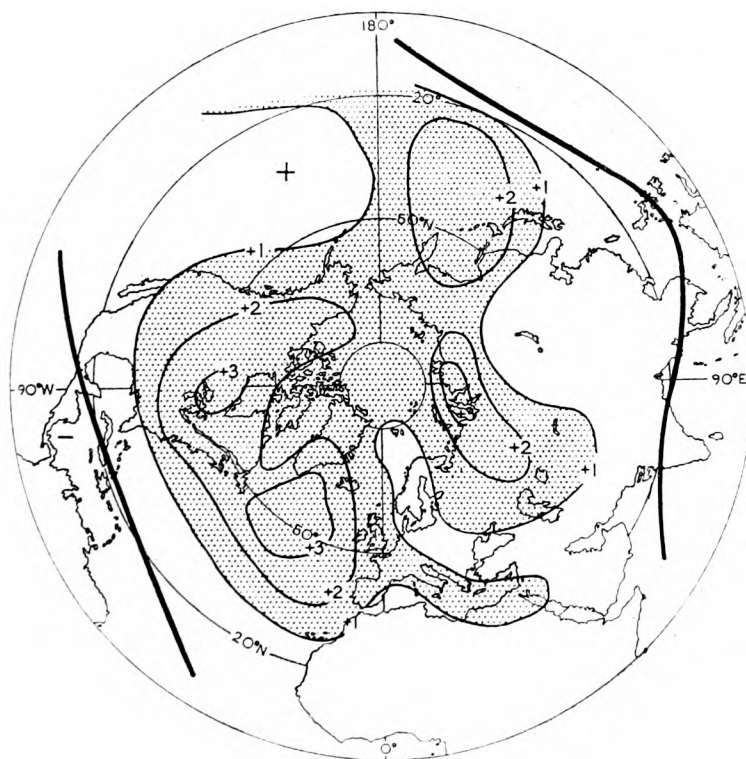


FIGURE 5—MARCH/APRIL

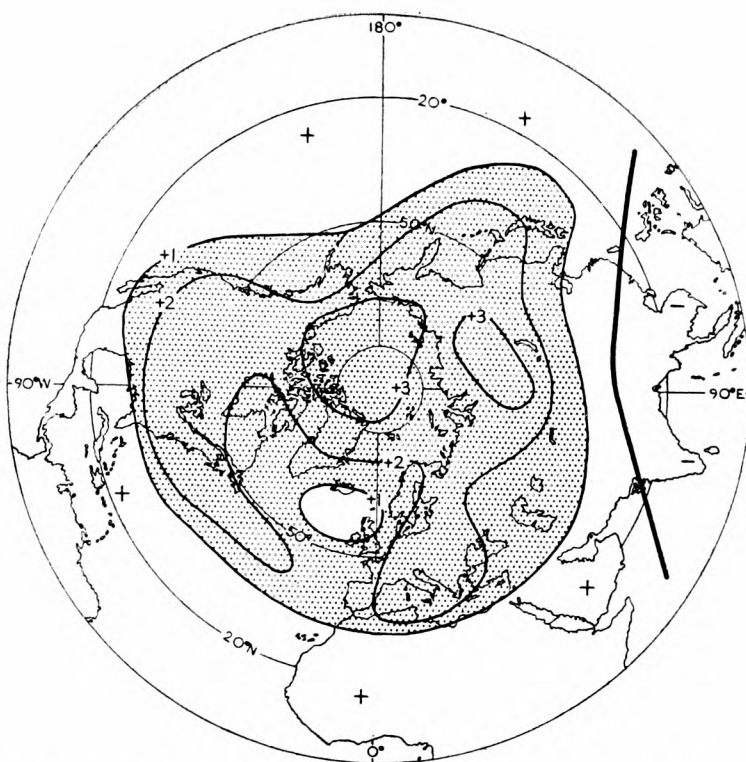


FIGURE 6—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, APRIL/MAY

Unit: $10^{-4} \text{g cal cm}^{-2} \text{s}^{-1}$

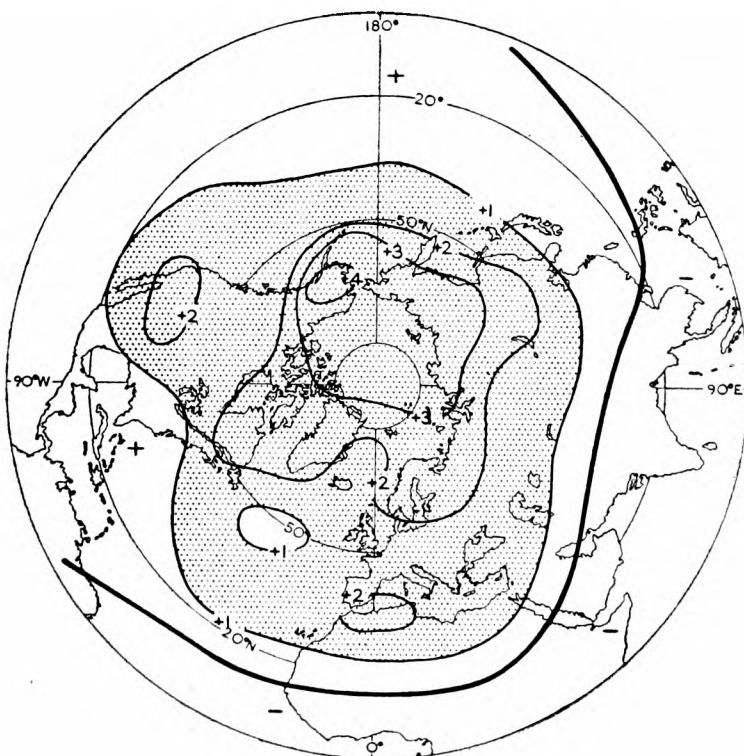


FIGURE 7—MAY/JUNE

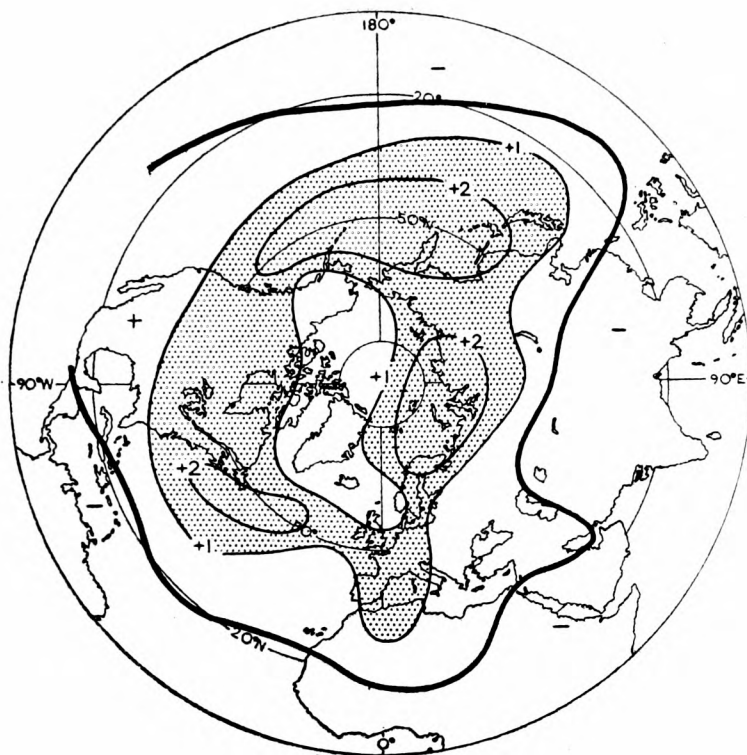


FIGURE 8—JUNE/JULY

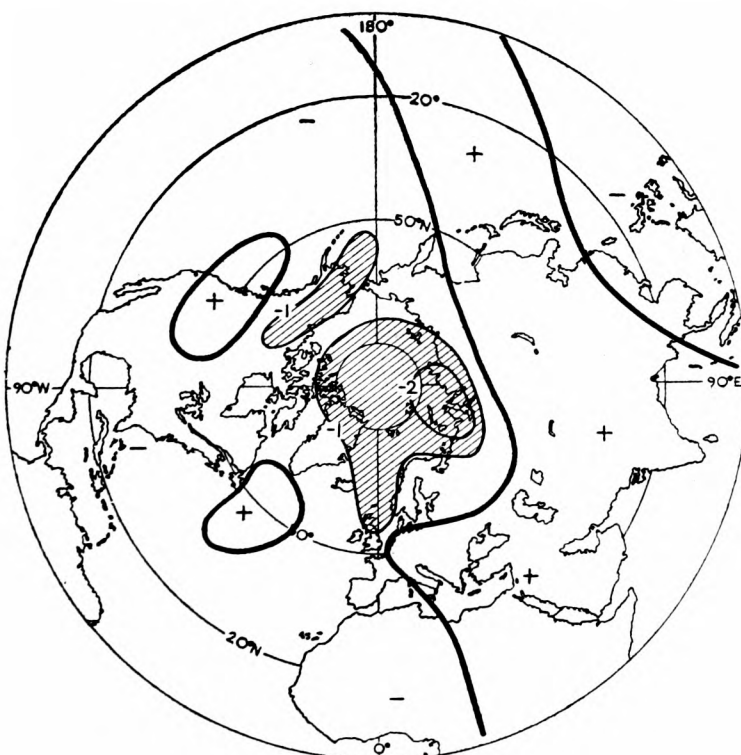


FIGURE 9—JULY/AUGUST

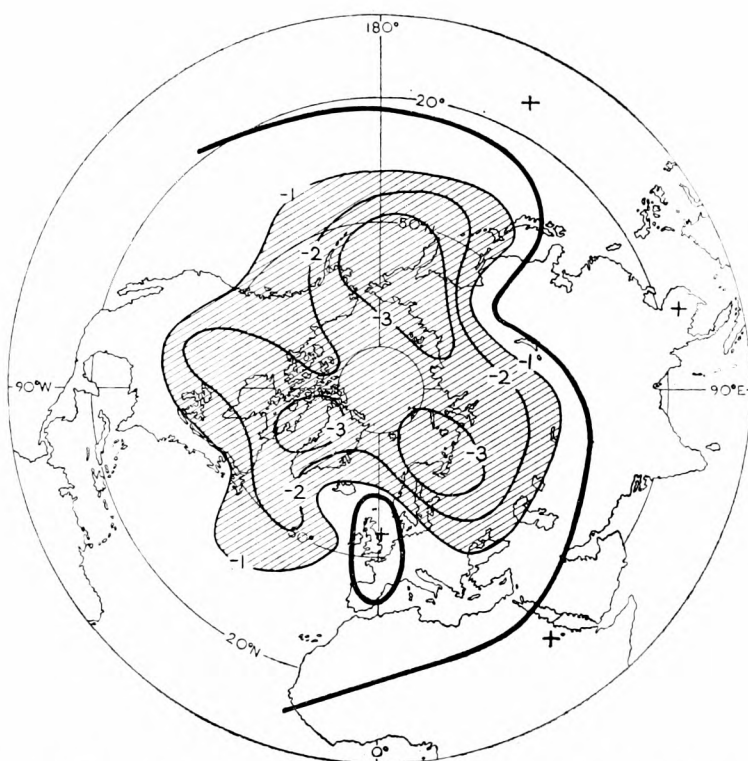


FIGURE 10—LOCAL RATE OF CHANGE OF THE TOTAL HEAT CONTENT OF THE TROPOSPHERE IN THE NORTHERN HEMISPHERE, AUGUST/SEPTEMBER
Unit: $10^{-4} \text{g cal cm}^{-2} \text{s}^{-1}$

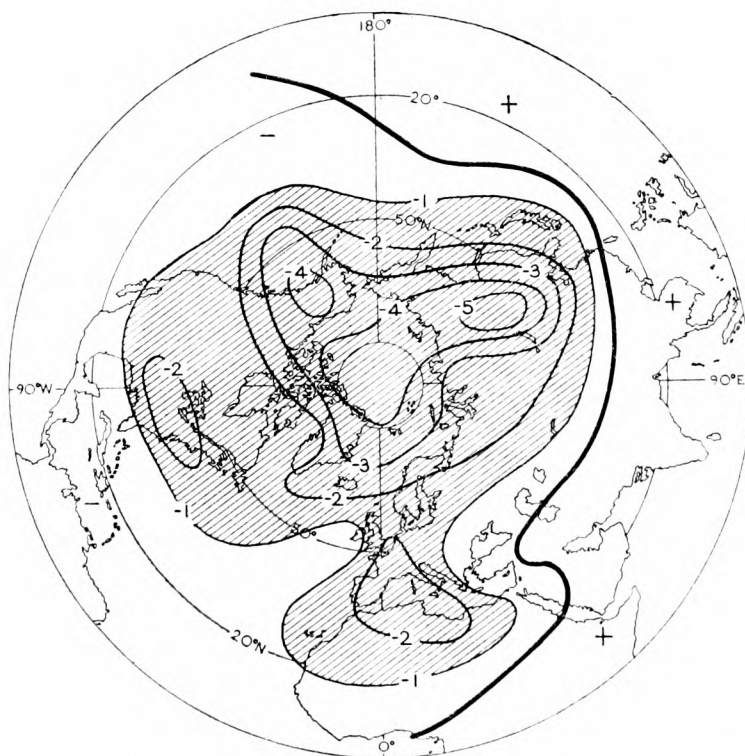


FIGURE 11—SEPTEMBER/OCTOBER

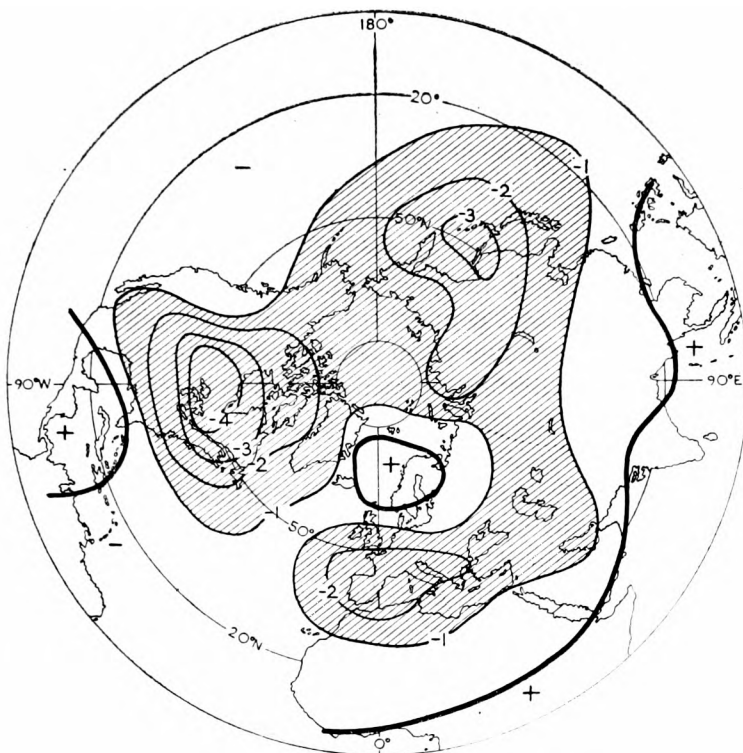


FIGURE 12—OCTOBER/NOVEMBER

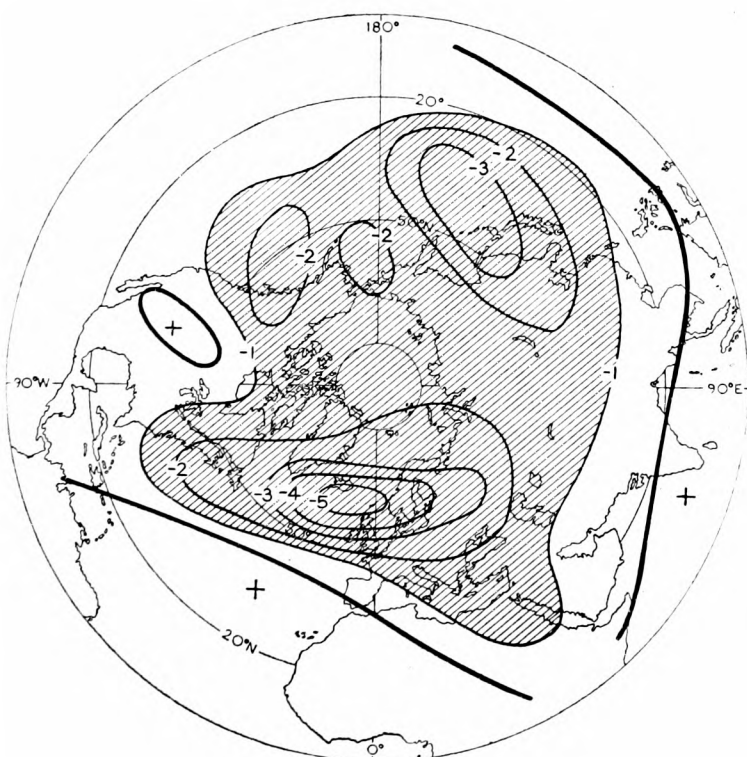


FIGURE 13—NOVEMBER/DECEMBER

Conclusion.—Although the charts given here simply depict the seasonal march of temperature in the northern hemisphere troposphere, several interesting aspects of the geographical distribution are revealed. On a global scale, cooling commences in an area near the pole in late summer and strengthens and spreads in a more or less axially symmetrical way until late autumn and early winter when asymmetry becomes most pronounced. The most intense cooling of over $5 \times 10^{-4} \text{ g cal cm}^{-2}\text{s}^{-1}$ occurs in the north-west Atlantic in early winter. The reverse is true of warming when in late winter and early spring there is pronounced asymmetry in the pattern; in late spring and early summer the pattern is more uniform and centred on the pole. Longitudinal variations are therefore features of several charts but there is no obvious relation between these variations and the pattern of land/sea distribution.

The winter patterns of local heating and cooling (Figures 2 and 3) bear little resemblance to the charts of heat sources and sinks for a normal winter, given for example, by Clapp¹, and have values an order of magnitude lower. This strongly suggests that any attempt to use equation (1) to estimate the pattern of local heating (e.g. Adem⁵) is unlikely to be successful unless the effects of redistribution of heat by atmospheric motions are adequately represented. Shaw³ presents strong evidence to suggest that this cannot be done simply by relating these effects to the mean temperature field using a form of large-scale 'austausch' coefficient.

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551.501.5:551.571.7

A USEFUL SYNOPTIC REPRESENTATION OF MOISTURE

By T. H. KIRK

Most synoptic meteorologists would agree that, in present practice, inadequate attention is paid to variations of humidity. Although it is true that individual radiosonde ascents are studied in detail, the systematic charting of humidity has not yet been regarded with much favour and, hitherto, little advantage has been derived from this approach.

At the British Central Forecasting Office (CFO), Bracknell, charts are drawn depicting the dew-point depression at the 700 mb level. The practice is to mark areas where the dew-point depression is less than 5°C (i.e. moist) and areas where the dew-point depression is greater than 20°C (i.e. dry). Although easy to construct, these charts are of limited use chiefly because of the large fluctuations in the positions of the critical lines. These fluctuations may be real as, for example, in situations where the humidity decreases rapidly at a level near the 700 mb surface, or fictitious because of the limitations of humidity measurement. Perhaps the main difficulty, however, is that a value applicable to a particular level cannot be regarded as representative of a layer.

For many purposes it would appear reasonable and profitable to treat humidity on a 'layer' basis, much as temperature has been treated in terms of 'thickness'; for example the mean dew-point depression taken over the layer 1000 mb to 700 mb might confidently be expected to be more representative than a spot value and the humidity patterns drawn in terms of mean values should show greater continuity and conservation. To work out mean values using observations from several levels would be tedious and, where the dew-point fluctuates erratically, the final result would depend on the particular points chosen unless these were numerous.

This procedure may be avoided by the concept of 'dew-point thickness' which may be defined as the thickness of the layer, say 1000–700 mb, on the assumption that the dew-point curve is treated as a temperature curve. In other words, the dry-bulb temperature curve defines the true thickness whereas the dew-point temperature curve, treated as a temperature, defines the 'dew-point thickness'. The same procedure, graphical or numerical, for determining the thicknesses may be used for both.

If T ($^{\circ}\text{A}$) be the dry-bulb temperature and T' ($^{\circ}\text{A}$) the dew-point, then $T - T'$ is the dew-point depression. To get an average value over a layer the dew-point depression must be integrated with respect to the vertical co-ordinate. Therefore, using the logarithm of the pressure as the vertical co-ordinate,

$$\int (T - T') d(\log p) = \int T d(\log p) - \int T' d(\log p)$$

$$\text{and therefore } -\frac{R}{g} \int (T - T') d(\log p) = -\frac{R}{g} \int T d(\log p) + \frac{R}{g} \int T' d(\log p),$$

where R and g have their usual significance.

But $(-R/g) \int T d(\log p) = h$, where h is the thickness of the layer between the two chosen standard pressure levels, while $(-R/g) \int T' d(\log p)$ is the corresponding 'dew-point thickness'.

It is therefore possible to write

$$-\frac{R}{g} \int (T - T') d(\log p) = h - h',$$

and this gives the result that the difference between the thickness and the 'dew-point thickness' of a layer is a measure of the average dew-point depression. Just as h may be regarded as representative of the average temperature of a layer, so h' may be regarded as representative of the average dew-point. The technique therefore permits the easy evaluation, for any layer, of the average dew-point and the average dew-point depression.

This method has been used, with limited data, for the 1000–700 mb and 1000–500 mb layers and charts have been drawn depicting these quantities. Experience shows that the 'dew-point thickness' is, in general, related to the frontal analysis as would be expected on conventional air-mass considerations. The detail, showing variations from one chart to the next, can be of assistance in the interpretation of frontal structure and activity. The 'dew-point thickness depression' measures the departure from saturation of the layer and is naturally inversely correlated with areas of cloudiness and precipitation.

Figures 1–4 show the distribution of 'dew-point thickness' and 'dew-point thickness depression' for the 1000–700 mb layer for 1200 GMT on 9 December and 0000 GMT on 10 December 1964. The isopleths, in units of 5 decametres,

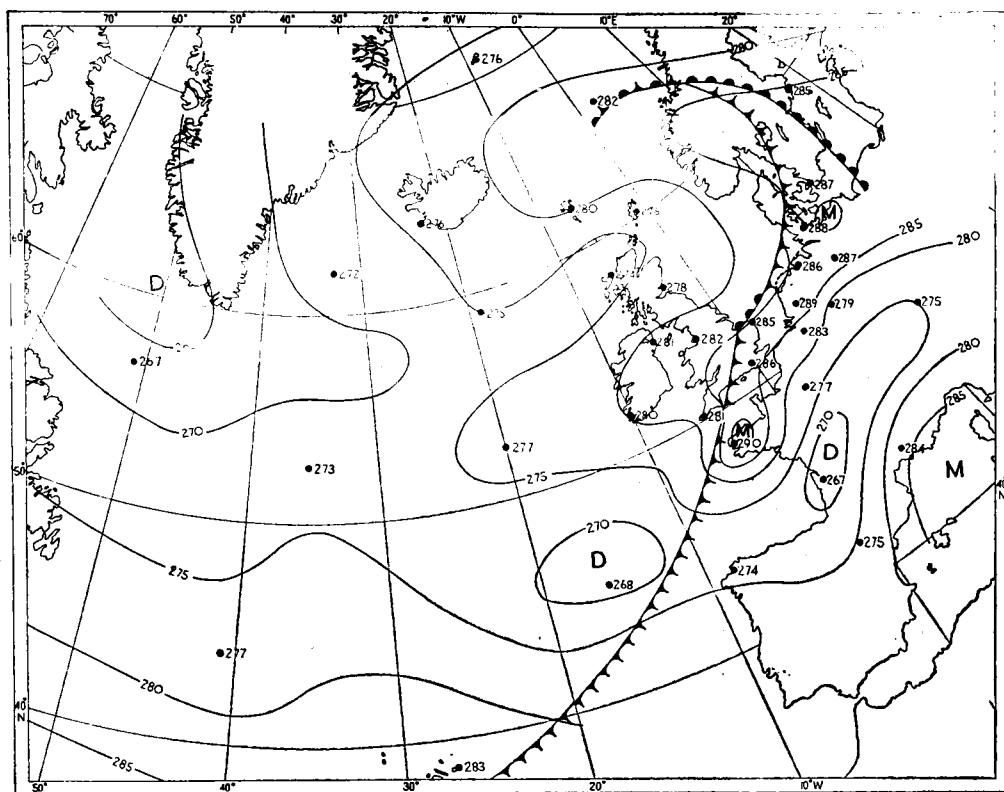


FIGURE 1—'DEW-POINT THICKNESS', 1000-700 MB, 1200 GMT 9 DECEMBER 1964
Thickness values and isopleths are in decametres; the former values are plotted on the right of the station position.

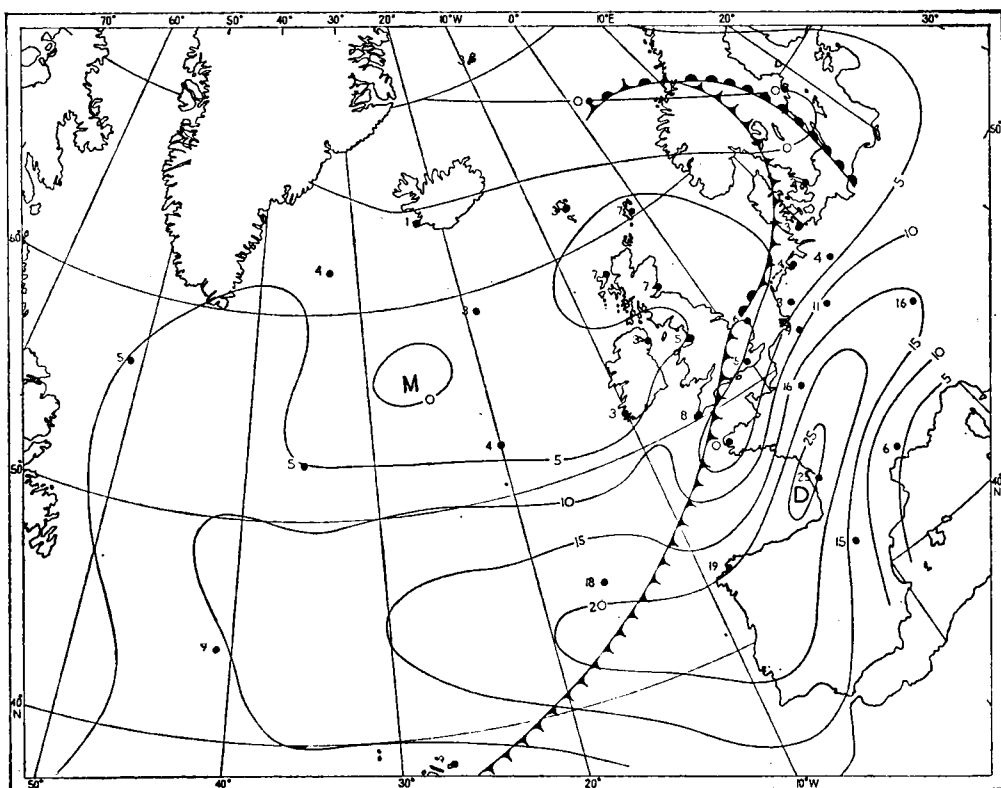


FIGURE 2—'DEW-POINT THICKNESS DEPRESSION', 1000-700 MB, AT 1200 GMT ON
9 DECEMBER 1964
The 'dew-point thickness depression' is plotted on the left of the station position in decametres.

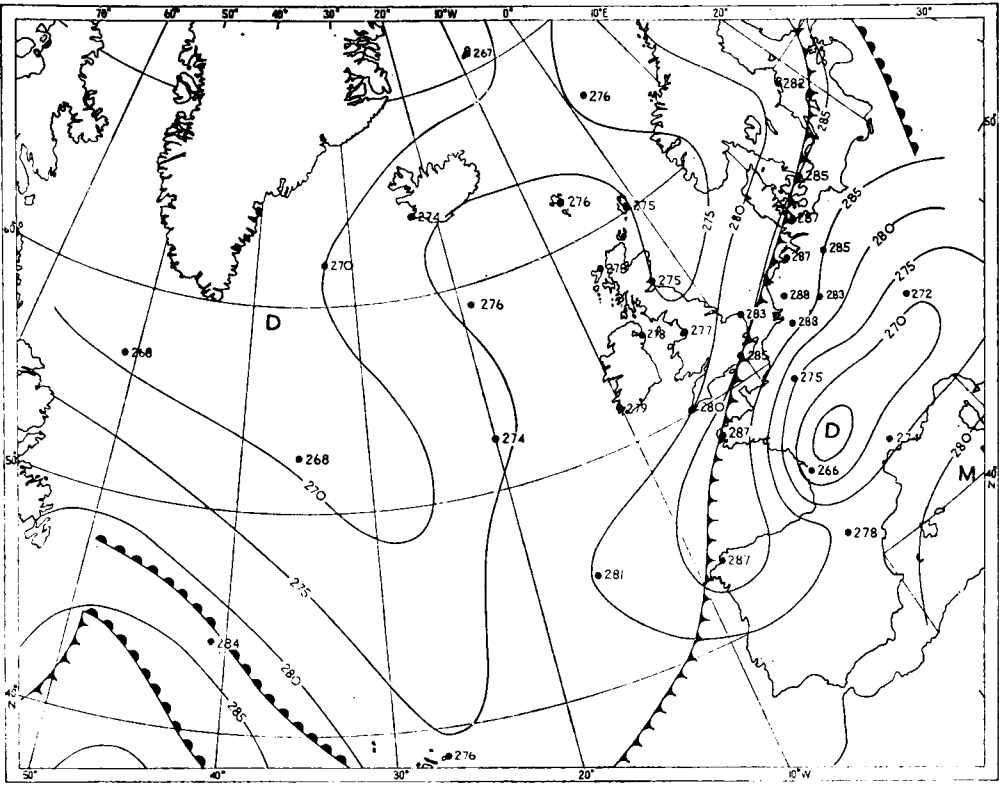


FIGURE 3—‘DEW-POINT THICKNESS’, 1000-700 MB, 0000 GMT 10 DECEMBER 1964
Thickness values and isopleths are in decametres; the former values are plotted on the right of the station position.

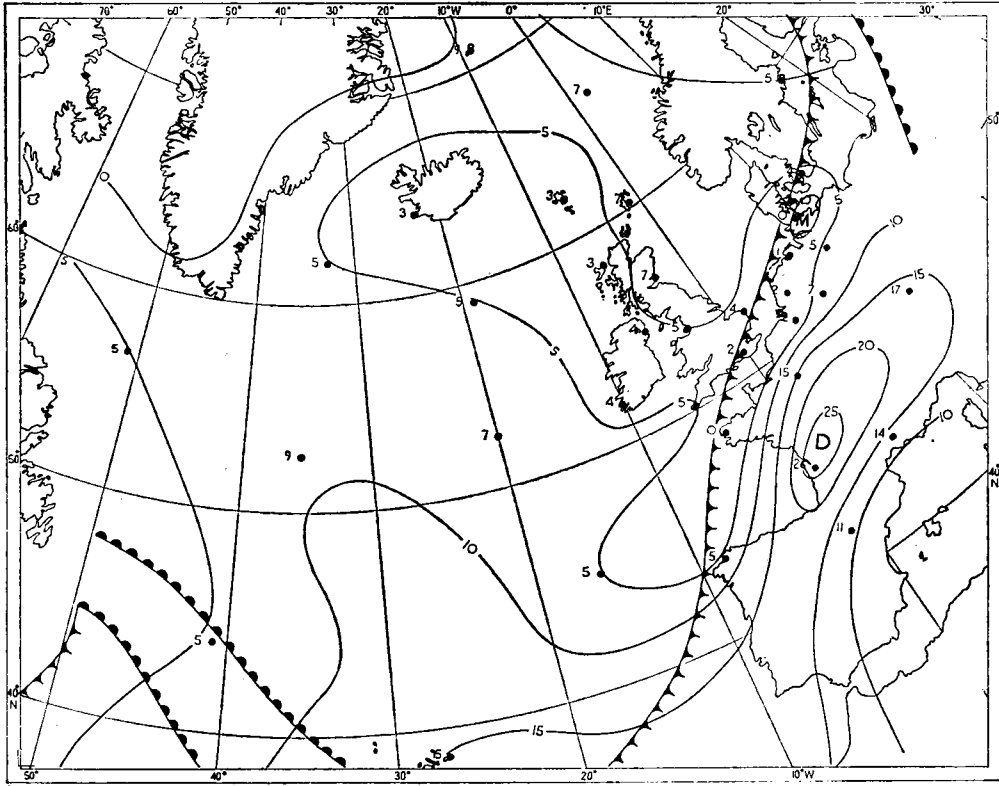


FIGURE 4—‘DEW-POINT THICKNESS DEPRESSION’, 1000-700 MB, AT 0000 GMT ON
10 DECEMBER 1964

The ‘dew-point thickness depression’ is plotted on the left of the station position in decametres

were drawn independently using the values shown at each station and the fronts were taken from the CFO facsimile charts and superimposed without amendment.

It is outside the scope of this note to discuss these charts in detail; they are presented solely as an illustration of the potential value of the method. There is, of course, no restriction to the particular layers chosen; charts may be drawn for any layer for which humidity observations are available. Temperature parameters other than dew-point could also be used in a similar way.

It is noted that Swayne¹ makes a somewhat analogous use of thickness in which precipitable water is related to 'saturation thickness'. This is defined as the thickness between the specified constant-pressure surfaces of a saturated pseudoadiabatic column having the same precipitable water value as the observed column.

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A NOTE ON THE OBJECTIVE LOCATION OF FRONTAL ZONES

By P. E. CARLSON, J. L. GALLOWAY and P. C. HAERING

A relatively short paper by R. J. Renard, U.S. Naval Postgraduate School and L. C. Clarke, U.S. Navy Fleet Numerical Weather Facility, Monterey, California, slipped unobtrusively into the General Session I of the 45th Annual Meeting of the American Meteorological Society in New York on 27 January 1965, marks another step forward in the development of objective frontal analysis.

Although meteorologists welcomed the Bjerknes model of the extratropical frontal depression nearly 50 years ago there has never been any international agreement on how and where in any particular case the fronts should be drawn. The United Nations Educational Scientific and Cultural Organization/World Meteorological Organization seminar on Mediterranean synoptic meteorology in 1958¹ probably came as near as anything to some kind of unanimity in this field. The placing of fronts has been the work of individuals and even within services a common form of training has not produced an overall entirely objective form of analysis. It is true that the Russians have a two-front model but there can be no doubt that the first attempt in the west to systematize frontal analysis throughout the troposphere was the work of Canadian meteorologists in the years succeeding World War II. The work was publicized by the Royal Meteorological Society and the American Meteorological Society and was the subject of an address by Professor B. W. Boville to the Meteorological Office in 1955² but it has not yet caught on. Mr. J. S. Sawyer in his Presidential Address to the Royal Meteorological Society in 1964 remarked "it is probably an attempt to force nature into an over-rigid model which has limited the interest in frontal contour analysis."

What the Canadians did was to locate baroclinic zones at the 500, 700 and 850 mb levels by means of thickness and isotherm gradients, insert fronts and extrapolate them upwards to the jet streams and downwards to the surface. In this way a reasonably objective self-consistent frontal analysis was obtained on a routine basis by subjective means.

Montreal meteorologists had a recent opportunity of hearing Professor Renard, who lectured in the Central Analysis Office (CAO) of the Canadian Meteorological Branch on 29 January, and who has made an extensive study of Canadian methods.

In Professor Renard's view an adequate amount of data containing frontal information is now being fed into computers to enable these machines, when properly programmed, to furnish an objective frontal analysis. He and Mr. Clarke have defined a frontal parameter which is used to locate objectively the frontal-zone boundaries as well as the maximum baroclinicity within the zone. The parameter, actually a form of the second derivative of a variable, is versatile to the extent that any conservative air-mass quantity may reasonably be used as the variable. Some amount of experimental work has been done with potential and equivalent potential temperature at the 1000 and 850 mb levels, as well as at the surface. A full report on the status of the frontal-analysis project has been submitted for publication in the *Monthly Weather Review* and is to be entitled 'Experiments in Numerical Objective Frontal Analysis,' by R. J. Renard and L. C. Clarke.

Northern hemisphere charts for 1 January 1965 were presented to illustrate results of the technique and reference to the CAO hand analyses for that day showed excellent agreement with the machine-computed fronts. The polar front was not being carried by the CAO as being too far south, over Central America, but the Maritime and Arctic fronts on the North American land mass came out of the comparison well, as did the Maritime front in the north-eastern Pacific. The numerical analyses picked out the cold-valued Arctic front (between tcA and cA) in the Canadian north-west.

One of the advantages of a systematic frontal contour analysis is the easy association of a front with a statistically determined range of temperatures. By mention of the name of the front one gets an immediate picture of the temperature field, tropopause height and so on. It is not too much to expect that in the near future meteorological satellites will be able to measure tropospheric temperatures and hence indicate the extent of each air mass—and the name of the front in any location.

It appears that synoptic frontal analysis is entering the machine and space age.

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METEOROLOGICAL OFFICE DISCUSSION

Hydrological forecasting

The last Monday discussion of the 1964–65 session was held at the Royal Society of Arts on 15 March. The opener, Mr. A. Bleasdale, briefly covered the range of topics which appear under the heading of hydrological forecasting in international literature. Some of these are not of great practical importance in the United Kingdom but are of obvious significance within other climatic régimes and hydrological environments, so that they form major sub-divisions

of a large and growing subject. Such items include the forecasting of seasonal and annual run-off, notably where melting snow contributes a large proportion, with a regular seasonal incidence, of the total annual flow; the prediction of the formation and break-up of ice on navigable rivers; and the forecasting, for lakes and other land-locked waters, of seiches or storm surges which, as on Lakes Manitoba and Erie, may have amplitudes up to 12 feet.

In the United Kingdom hydrological forecasting is, in practice, restricted almost entirely to the operation of flood-warning schemes, but with considerable interest from time to time in the eventual possibilities of developing techniques which would be useful in the field of water supply and the management of water resources. Flood-warning systems have been developed mainly by the engineers of river authorities (formerly river boards) in England and Wales, and the Meteorological Office has helped in the work in two main ways. In some cases, usually through outstations or Weather Centres, the Office is well equipped to provide information about the coming of rainfall which might cause flooding, or alternatively to advise on and help with the organization of prompt rainfall reports from voluntary observers. Secondly, for some years now the Climatological Services Branch has issued from Bracknell a series of maps showing estimated soil moisture deficits over the whole country. Though the maps are very generalized and on a very small scale, they provide a useful indication, much appreciated by the river authority engineers for whom they are primarily intended, of the development of susceptibility to flooding as soil moisture deficits decrease.

The opener touched on the possibility of using radar to make areal assessments of rainfall for use in flood-warning schemes, but it was left to Dr. Caton in a major contribution to the general discussion to enlarge on this theme. Most of the remaining discussion was concerned with radar techniques of rainfall measurement, or with experience at outstations and Weather Centres in collaborating in flood-warning work. It was particularly stimulating to hear in this way of the contacts which have been established, and in closing the discussion the Chairman, Dr. A. C. Best, commented on the interesting contributions which had been made.

551.5:061.3

THIRD ASSEMBLY OF THE SPECIAL COMMITTEE FOR THE INTERNATIONAL YEARS OF THE QUIET SUN, MADRID, 1965

The Third Assembly of the ICSU (International Council of Scientific Unions) Special Committee for the International Years of the Quiet Sun (IQSY) was held in Madrid between 28 March and 3 April, 1965. Some 150 scientists, from 35 countries and many disciplines, attended.

The main purpose of the assembly was to have prepared, and accepted, reports of the many Working Groups. Most of these reports contained a recommendation urging the continuance of programmes initiated or intensified during the IQSY. Reluctance to see programmes close down, or to see them reduced, is, I suppose, natural. Yet the whole concept of periods such as the IGY and the IQSY is to concentrate effort into *limited intervals*. This urge to keep them all going may not, in the long run, be in the best interests of science.

The Meteorological Working Group also recommended the continuation of the World Day Programmes and of STRATWARM alerts. The group recommended, too, that the World Meteorological Organization should arrange for the central collection and publication of meteorological rocket data and of noctilucent cloud data on the lines of the existing collection and publication of ozone and radiation data.

In addition to Working Group activities there were a number of review papers. From Mrs. Dodson-Prince, of the solar activity discipline, came a report on how 'quiet' the sun in fact is during this Quiet Sun period. Solar activity is never the same from one cycle to the next and the present 'minimum' has, it seems, been exceptionally different. The actual minimum seems to have occurred in June last year, in the sense that solar activity of the new cycle then began to appear (sunspots can be identified as belonging to the old, or to the new, cycle by their 'polarity'). However, there has still been little decrease in old cycle activity, so that the minimum was not very marked. It was suggested, indeed, that when the old cycle does die there may be a secondary minimum as did occur once last century. The new cycle is itself anomalous in that, of the large number of sunspots so far recorded, all save one have been in the 'northern' hemisphere. Usually they are more or less equally distributed between the hemispheres. A similar uneven distribution was recorded long ago but, I gathered, this had until now been regarded with suspicion.

From the meteorology discipline Dr. Godson reported further on his investigations into quasi-biennial oscillations. If I understood him correctly, he finds that, whereas in tropical latitudes the oscillations show a well-defined 'period' of just short of 26 months, with no discernible variation of period or phase with longitude, at higher latitudes not only are the oscillations weaker, as is well known, but the phase of the oscillations varies with longitude, and the 'period' becomes less well defined. To some members of the audience the curves which he presented for these higher latitudes were hard to distinguish from curves of 'noise' but Godson, emphasizing similarities between curves prepared from what he recorded as independent sets of data (sets relating to different geographical areas—there are not yet sufficient data to study different epochs separately) expressed some conviction that there really is not just a single quasi-biennial oscillation with period close to 26 months, but a whole collection of oscillations with periods ranging between 18 and 30 months. No mechanism for the maintenance of even one, let alone a family, of such oscillations being known, Godson, likening the atmosphere to a clock with no perceptible pendulum or balance wheel, remarked that it was truly a 'cuckoo' clock and perhaps a somewhat 'alarming' one too.

From the ionospheric discipline Mr. Shapley described an investigation into a correlation between the absorption of radio waves in the ionosphere at round about 90 km, and the temperature in the lower stratosphere. He had taken 16 cases where a stratospheric warming, lasting for a few days, occurred over Berlin, the 30 km temperature curve showing a marked peak, and he demonstrated that there was a strong tendency for a similar peak to occur in the ionospheric absorption curve at precisely the same time. Did the atmosphere at 90 km, he asked, know what was happening at 30 km?

R. FRITH

REVIEW

Atmospheric radiation; Volume I. *Theoretical basis* by R. M. Goody. 9½ in × 6 in, pp. xi + 436, illus., Clarendon Press, Oxford University Press, Oxford, 1964. Price: 75s.

This is the second of the Oxford Monographs on Meteorology (editor P. A. Sheppard) which are intended to deal thoroughly with the basic theory of the subject and provide standard references and textbooks at university post-graduate level. In it Professor Goody has provided a comprehensive presentation of the problems of atmospheric radiation based on the fundamental laws of physics and applicable to planetary atmospheres in general. The treatment is erudite and, before he can hope to appreciate its contents, the student will have to know his basic physics and mathematics well. A useful list of references to source books and original papers is given at the end of each chapter together with advice on further reading. Extensive appendices are also provided on such subjects as spectroscopic units, model atmospheres, the physical state of the sun, optical properties of water and ice, the principal functions used in radiation calculations, etc. In general the subject matter is restricted to basic theory, spectroscopy, computation methods, etc. and their application to theoretical problems. It is hoped that a companion volume will ultimately be produced to deal with practical aspects such as instrumentation, radiation climatology, etc.

In his introductory chapter the author first outlines the nature of the problem. As the source of virtually all the earth's energy is solar electromagnetic radiation, the absorption of parts of the solar spectrum at different levels in the atmosphere, the earth's albedo, and absorption at the surface are first considered. The emission of low-temperature thermal radiation must closely balance in the mean the absorption of the solar radiation and this establishes the mean atmospheric temperature, whereas unbalance between latitudes leads to the general circulation. The solar radiation is virtually confined to wavelengths below about 4μ while the terrestrial radiation is mainly above 4μ , so that they can be treated separately. Since N_2 , O_2 , and A are almost transparent to radiation of the longer wavelengths, it is the minor polyatomic constituents which are important in terrestrial radiation and their effects are therefore to be studied in detail. Further sections in this chapter outline the thermal structure of the atmosphere and its chemical composition at different levels in some detail.

The author then gives in Chapter 2 a thorough treatment of the theory of radiative transfer in the atmosphere dealing first with extinction and heating. Emission is discussed in terms of the basic concepts of thermodynamic equilibrium and the interaction of matter and radiation. Finally the integral transfer equations are derived and the mathematical problems of obtaining the radiative fluxes and heating from them by numerical and also approximate methods, are discussed. These equations involve the complex absorption spectra of the radiatively important atmospheric constituents and Chapter 3 is therefore devoted to the theory of gaseous absorption and the physical processes determining these spectra. This includes much of the basis of spectroscopy including the behaviour of the various energy modes of the molecules (translational and the quantized rotational, vibrational and electronic modes) and the emissions or absorptions linked with transitions between the various energy levels. This leads

to the theoretical prediction of the spectra from the molecular structure and also, since the processes are not strictly monochromatic, the derivation of the Lorentz shape of the spectral lines and broadening due to Doppler and collision effects. Since the spectra are complex and have very fine structure it is necessary for both interpreting measurements and limiting computational effort to develop averaging techniques. Chapter 4 is therefore devoted to band models—infinite arrays of absorption lines with uniform statistical properties—which will simulate the true spectra. The discussion starts with single line models, which are chiefly of interest when the lines do not overlap but are necessary to introduce fundamental ideas such as the weak and strong line approximations. The chapter then discusses well-known regular models due to Elsasser and others and the random models first studied by the author himself. Questions of generalizing to models which are neither regular nor random and restrictions on model theory are considered in some detail. Chapter 5 is a detailed review of absorption data for N_2 , O_2 , H_2O , CO_2 , O_3 , N_2O , CH_4 and NO . Many figures and tables are given and 10 pages of references so that this is probably one of the most useful and up-to-date sources of data which are now readily available. Using these data and the theoretical ideas of the previous chapters, a discussion on the computation of fluxes and heating rates is given in Chapter 6. This involves the estimation of radiation transfer in the real inhomogeneous atmosphere and both theoretical and practical aspects are fully considered. These include such subjects as scaling approximations (of which that due to Curtis and Godson is probably the most successful), the treatment of diffuse radiation, calculations of direct heating by the solar beam, all the well-known radiation charts (e.g. Mücke-Möller, Yamamoto, Elsasser, Kew etc.), the previously unpublished Curtis two-parameter method of calculation and several other recent developments. There are many points of interest including an example of intercomparison of results using different radiation charts, and the reader will be disappointed to learn that there can be a spread of the order of 50 per cent in both fluxes and heating rates computed in this way. On the other hand, considerably greater accuracy is likely by using modern machine methods and it may soon be worthwhile to incorporate radiation data in numerical weather or general circulation prediction schemes (provided of course that other factors such as cloud formation can be properly specified).

The subject of extinction by molecules and droplets including scattering by large and small particles, geometric optics and Mie theory is dealt with in the next chapter. The basic problem of radiative equilibrium which bears on the general thermal structure of the atmosphere and the necessity for atmospheric motions is considered in Chapter 8. The outline of the underlying theory is followed by a longer discussion on the lower stratosphere, whose characteristic features are basically determined by radiation considerations, and the requirement for a convective troposphere below. This problem is of course a classical one associated with names such as Emden, Gold, Humphreys, Milne and more recently Simpson, Dobson, Goody himself and Manabe and Möller and the development of modern ideas is fully and clearly presented. Finally in the last chapter the interrelation of radiative transfer and fluid motions is discussed. The former affects the heating rate through the divergence of the radiation flux and the latter through that of the advective and turbulent fluxes. Practical applications include lower-troposphere problems such as the diurnal temperature wave, night cooling, the onset of cellular convection (which follows the

treatment of the author's previous papers on this subject) and the modification by radiation considerations of the Richardson criterion for the onset of turbulence.

In summary, this is clearly a very important book and is unique in its coverage of the present-day state of the subject so that it is a 'must' for meteorological libraries, research workers and advanced students. The production is excellent and the price very reasonable for a book of this standard.

R. J. MURGATROYD

OBITUARY

Mr. H. T. Smith.—It is with very deep regret that we have heard of the death of Mr. H. T. Smith on 5 April 1965. An appreciation of his many years of service in the Office appeared in the March, 1958 issue (page 94) of this magazine. Our deepest sympathy is extended to his widow and family in their sad loss.

D.J.W.

METEOROLOGICAL ASSISTANT

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THE EFFECT OF CONTAMINATED MUSLINS AND WICKS ON WET-BULB TEMPERATURE READINGS

By W. D. S. McCaffery

Summary.—This paper describes an experiment made to discover the effect on readings of a wet-bulb thermometer of leaving the muslin and wick fitted to the instrument for long periods (up to six months), and gives some conclusions drawn from the results. The conclusions are used to suggest for how long instruments exposed on masts 1000 feet or more in height may be left unattended (provided an adequate water supply is maintained). A detailed discussion of the results is given in an unpublished paper, *Wet-bulb temperatures—a comparison between readings from clean and dirty instruments*, by W. D. S. McCaffery; this paper is available on loan from the Meteorological Office Library.

Introduction.—A method of obtaining profiles of temperature, humidity and wind in the lowest 1000 feet or so of the atmosphere is to mount instruments at several levels on tall masts. Instruments so mounted are not always readily accessible for maintenance, consequently it is of some interest to study how atmospheric pollution of all sorts, accumulating on unchanged muslins and wicks of wet-bulb thermometers, affects the readings of the instruments.

Measurements made by Lawrence,^{1,2} suggest a variation of atmospheric pollution with height, the level of maximum concentration being related to the height of pollution sources (e.g. chimneys) in the area. The measurements were made, not in the free atmosphere, but near the ground at sites up a steeply sloping hillside; the results, nevertheless, may be significant close to sources of pollution and in hilly districts where the level of maximum concentration may depend on the height of hills between the source and the site of the measuring instruments.

Lawrence also found a seasonal change in the vertical distribution of atmospheric pollution, the pollution in winter being approximately twice that measured in summer at heights up to about 1200 feet above MSL (about 700 feet above valley level).

Another result reported by Lawrence is the direct dependence of accumulated pollution on the run-of-wind. The flow of air through a screen, especially a single-louvered screen, at heights up to several hundreds of feet above ground level is likely to be significantly different, in the mean, from the flow of air through a standard thermometer screen housing instruments at 4 feet above the ground. Consequently the dirtying of a wet-bulb muslin and wick at a hundred or more feet above ground level may proceed much faster than at the ground.

It follows that the length of time a wet-bulb muslin and wick may reasonably be left unchanged, depends on the height of the instrument above the ground and the effectiveness of the sheltering screen in regulating the flow of air past the thermometer bulb. Other important factors are the surrounding topography and pollution sources, season of the year, direction and speed of the mean wind, and also significant departures from the mean on particular occasions. Lawrence's measurements were made in a hilly district away from the sea in Lancashire at Helmshore, a rural site almost encircled by industrial areas of Lancashire and the West Riding of Yorkshire. His results, therefore, may not be valid in coastal regions where, with winds off the sea, the pollution is different and the source is at the surface; nor may they be entirely valid in relatively flat inland areas. The required answer may be obtained, ideally, only by testing at each observing level at each mast site.

In the absence of data from masts, and because the method was simple and easy to organize, tests were arranged with instruments exposed at the standard height of 4 feet in thermometer screens at ground level.

Acceptable practice for ensuring a suitable standard of cleanliness, and hence of accuracy, of wet-bulb thermometers exposed in thermometer screens, is described in standard reference sources.^{3,4} Experiments to determine the rate and extent of the deterioration in efficiency of a wet-bulb thermometer have been made by Sutcliffe,⁵ Garnett⁶ and Durward,⁷ while other relevant experiments have been described by Whipple^{8,9} and elsewhere in the *Meteorological Magazine*.¹⁰ The present experiment extends such work to a number of varied locations, including rural, semi-rural and urban areas, coastal areas and ships at sea.

Nature of the experiment and stations participating.—At each station a second wet-bulb thermometer was suspended from the roof of the thermometer screen closely alongside the standard wet-bulb instrument, which was maintained in the usual way and referred to as the clean wet-bulb (*C*). Once the second wet-bulb thermometer was mounted in the screen, the muslin and wick were left unchanged throughout the course of the experiment, the thermometer being referred to as the dirty wet-bulb (*D*). The experiment commenced at Bracknell on 8 January 1964 and was soon extended to Kew where readings began on 5 February. At Bracknell readings were recorded at 0900 GMT on five days each week; at Kew readings were recorded daily at 0900 GMT, and on most days at 1200 and 1500 GMT as well.

After nearly 11 weeks at Bracknell and 7 weeks at Kew, during which time only occasional differences of 0.1°C , and very occasional differences of 0.2°C or 0.3°C were observed between the two wet-bulb readings, it was decided that the results justified extending the experiment to include records from areas where the effects of industrial and urban pollution might be greater than at Kew, and also to examine the effects of proximity to the sea. The stations listed in Table I were selected to participate in the experiment, most of them commencing the comparison of readings early in April 1964. At this stage the co-operation of the Marine Branch of the Meteorological Office was invited and as a result arrangements were made for two Ocean Weather Ships to take part, returns being received from OWS *Weather Surveyor* and OWS *Weather Monitor* covering voyages made between May and October 1964.

TABLE I—STATIONS PARTICIPATING IN THE EXPERIMENT

Bracknell	Initial pilot experiment			
Kew	Initial urban area station			
Eskdalemuir	Clean air station			
Birmingham Airport	Urban/industrial area station			
London Weather Centre	"	"	"	"
Manchester Weather Centre	"	"	"	"
Acklington	Coastal or near coastal station			
Benbecula	"	"	"	"
Leuchars	"	"	"	"
Mount Batten	"	"	"	"
Valley	"	"	"	"
Wick	"	"	"	"
<i>Weather Monitor</i>	Ocean Weather Ship			
<i>Weather Surveyor</i>	"	"	"	"

Participating stations were asked to make returns of corrected temperature readings made at 0600 and 1500 GMT—times likely to be near periods of maximum and minimum relative humidity—and also at other times during the day if the difference, $D-C$ between readings of the dirty and clean wet-bulb thermometers was greater than that recorded at either 0600 or 1500. Wind speed and direction were also listed and any relevant remarks. Readings were continued until 31 October 1964. At Bracknell, after approximately 6 months, the dirty muslin and wick were replaced by a clean set on 1 July and a second series of readings was started. At Manchester Weather Centre a similar change was made on 8 July. At all the other land stations the muslin and wick on the dirty wet-bulb thermometer were left unchanged throughout the experiment.

Ocean Weather Ship *Weather Surveyor* made three voyages between May and September 1964 with the same muslin and wick on the second wet-bulb thermometer. The (portable) marine-type thermometer screen was removed inside during spells in harbour. A fourth voyage was made in September/October with new equipment and with clean muslins and wicks on both wet-bulb instruments at the beginning of the voyage.

Ocean Weather Ship *Weather Monitor* also made four voyages between May and October. On this ship clean muslins and wicks were fitted at the beginning of all four voyages. New thermometers and screens were fitted for the fourth voyage.

Sources of error in psychrometry.—The determination of humidity with a psychrometer depends on the measured air temperature and the temperature depression of the wet element. The uncertainty in the derived relative humidity (or dew-point) is due principally to that in the temperature depression. For example, at 10°C , with a true depression of 5°C , a one degree error in dry-bulb temperature leads to an error in relative humidity of about 2 per cent while a one degree error in temperature depression yields an error of about 12 per cent. At the same dry-bulb temperature, corresponding errors in dew-point are approximately 1.5°C and 4°C , with errors in the depression of the dew-point below the dry-bulb reading—which is of importance to the fore-caster—of 0.5°C and 4°C . The magnitude of the error in relative humidity, for a given error in depression of the wet bulb, increases with decrease in dry-bulb temperature, the increase becoming marked at temperatures near and below 0°C . Thus, for a certain error in wet-bulb depression, the resulting error

in relative humidity may be acceptable at dry-bulb temperatures greater than a particular value, but not at temperatures lower than such a value. Table II shows the approximate change in relative humidity and in dew-point for a change in the wet-bulb temperature of 0.5°C at different dry-bulb temperatures.

TABLE II—APPROXIMATE CHANGE IN RELATIVE HUMIDITY AND IN DEW-POINT WHEN THE WET-BULB DEPRESSION CHANGES BY 0.5°C

Dry bulb $^{\circ}\text{C}$	Change in relative humidity <i>per cent</i>	Change in dew-point $^{\circ}\text{C}$
20	4	1
15	5	1
10	6	1
5	8	2
0	10	2
-5	13	3
-10	18	4

Errors occurring in the temperature depression are of two kinds, those which are effectively equal to a constant fraction of the temperature depression and those which form a constant additive part of the depression. Errors of the first kind may be unimportant at high humidities while being serious at low humidities; errors of the second kind may be important at all humidities. The forecaster is most interested in accurate measurements of high humidities, though climatologists and others may wish for a similar accuracy at all values of humidity.

A detailed list of errors in psychrometry is given by Wylie.¹¹ Those most likely to be significant in measurements made in thermometer screens are due to:

- (i) Inadequacy or imperfection of the covering of the wet bulb and of the water supply to it,
- (ii) The presence of substances which affect the vapour pressure over the water on the wet bulb,
- (iii) Variation of the assumed rate of ventilation (due to opening of the screen door and/or length of time it is left open);
- (iv) The temperature of the wet bulb influencing that of the dry either by free or forced convection, or by radiation;
- (v) Temperature gradients in the neighbourhood of the wet and dry elements;
- (vi) A high rate of change of atmospheric conditions (involving the time lag of the thermometers).

The last two sources of error lead to errors of the second kind mentioned above, the others give rise to errors of the first kind.

The object of the experiment was to discover the time taken for errors due to (i) and (ii) above to become significant. The interpretation of the results is complicated by the presence of errors due to other causes.

Results of the experiment.—A detailed discussion of the results is available elsewhere¹² and only a brief account will be given here.

Errors in psychrometry (apart from ventilation errors and errors in the thermometers themselves) operate in such a direction as to increase the observed relative humidity.¹³ Increasing pollution (of the dirty instrument) should therefore lead to increasingly positive differences $D-C$. While there was some evidence that this in fact occurred, practically all stations recorded numerous occasions when the depression of the dirty wet-bulb thermometer was greater than that of the clean. A close examination of the results, in conjunction with the examination of hygrograph records, indicated that some, but not all, of the negative values for $D-C$ occurred on occasions of rapidly changing humidity and could be accounted for by assuming a difference in the lag coefficients of the clean and dirty instruments.

At some stations negative values of $D-C$ recurred after a long series of increasing positive ones. It was also noticed at other stations, notably Kew Observatory, that after a period of increasing positive $D-C$ values over a period of some weeks a sudden and marked improvement in the efficiency of the dirty instrument occurred with much reduced positive values of $D-C$.

Apart from the somewhat anomalous results mentioned above, the most surprising result of the experiment was the length of time the dirty instruments remained reasonably efficient, with errors no greater than those which from time to time occur in wet-bulb instruments treated according to standard practice. It is also surprising that even after the muslin on a wet-bulb thermometer becomes visibly polluted the resulting errors may be very small. In smoky areas, errors can become large, but nevertheless may remain quite small for long periods of time. The most consistent results, with only small differences between the two wet-bulb thermometers, were obtained from Eskdalemuir, but results were nearly as good from Bracknell and Kew. London Weather Centre showed a greater range in the recorded $D-C$ values, especially at first, but only a very slight increase in the weekly root-mean-square $D-C$ value over a period of 30 weeks.

Results from Manchester Weather Centre and Birmingham Airport showed a more rapid and larger decrease in efficiency of the dirty wet-bulb thermometer at these stations when compared with the results mentioned above, the instrument at Manchester tending to act more like a dry-bulb thermometer after about 9 weeks.

From the coastal stations taking part in the experiment the results lay somewhere between those from the two groups of stations already mentioned, none of the instruments showing the very marked decrease in efficiency characteristic of the later stages of the experiment at Manchester and Birmingham. A feature of the results was the numerous reports, on occasions of high humidity, of the dirty wet-bulb thermometer reading higher than the dry-bulb thermometer; an explanation of this phenomenon is given by Gregory and Rourke¹⁴ on the basis that the saturated vapour pressure over a solution is less than that over a pure solvent and may even be less than the atmospheric vapour pressure.

Results from the weather ships were rather varied, indicating difficulties of obtaining satisfactory exposure and ventilation as well as variation in pollution rates with different wind and sea conditions. The results also indicated that for several weeks errors in readings from the dirty wet-bulb thermometer may be no bigger, though occurring more frequently, than those occurring on the first day of fitting a clean muslin and wick to the standard instrument.

Sometimes quite large errors can occur in readings of temperature and humidity made by experienced observers following standard practice. In an experiment carried out at Valley and Birmingham Airport over a period of 17 weeks, the differences between two quick readings of both the dry-bulb and wet-bulb thermometers were found to be $\geq 0.1^{\circ}\text{C}$ on 308 occasions and $>0.4^{\circ}\text{C}$ on 10 occasions.

Effective life of muslin and wick.—The experiment described was primarily an attempt to obtain information on how long a muslin and wick on a wet-bulb thermometer may be left unchanged without introducing unacceptable errors. For thermometers exposed in thermometer screens at ground level the results enable an estimate to be given dependent on some assumptions about the type of pollution. From these results we may infer how instruments exposed on tall masts 1000 feet or more in height may possibly be affected.

Where pollution concentration is very small (Eskdalemuir) errors are negligible for some weeks, and small, 3 or 4 per cent at 50 per cent relative humidity, after two or three months. There is no indication, even after 5 or 6 months, of the instrument becoming completely inefficient. At the other extreme (Manchester), where pollution is industrial or urban in origin, the wet bulb may completely fail to function after about 9 weeks and is probably too inefficient to be of use to the forecaster after about 3 or 4 weeks (though errors from other sources make this difficult to estimate). For inland stations, between these two extremes, returns from Bracknell, Kew, London Weather Centre and Birmingham Airport suggest that pollution effects may not become a source of error important to forecasters within a period of 2 or 3 months. (That London Weather Centre is like Kew rather than like Manchester Weather Centre may possibly be a result of the Clean Air Act. A report on the investigation of atmospheric pollution by the Department of Scientific and Industrial Research ¹⁵ shows that smoke concentrations in the vicinity of Kew and London Weather Centre are similar.)

The returns from coastal stations and the weather ships show a wide variation in the rate at which effects likely to be due to the accumulation of salt pollution become significant, and clearly wind speed and, at a coastal station, wind direction are important. Except, however, for instruments at the foot of a mast on or very near the coastline, the accumulation of salt on instruments several hundred feet above ground level is likely to be slow.

It may be inferred, therefore, that wet-bulb thermometers exposed on tall masts situated in areas not in the immediate neighbourhood of sources of heavy industrial pollution, are likely to remain effective instruments for up to 1 month or more and may retain an efficiency acceptable to forecasters for periods as long as 2 or 3 months, provided an adequate water supply is maintained.

Acknowledgement.—This experiment would not have been possible without the willing co-operation of the staff at Meteorological Office outstations and on Ocean Weather Ships, some of whom made helpful suggestions on the design of the experiment and the interpretation and analysis of the data.

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551.553.6:551.553.8:551.589.5

‘WINDINESS’ IN SHETLAND

By F. H. DIGHT, O.B.E., B.Sc.

Introduction.—A request from the research branch of the Forestry Commission (Scotland) for rather detailed information on the incidence of gales in Shetland for about the last 50 years for use in association with data on tree growth in experimental plantations, revealed a sequence of variations in storminess which it is thought may be of wider interest. There is some evidence of decreased windiness in the last 15–20 years and periods of decreased windiness at Lerwick have an apparent association with cold winters in Scotland.

Data.—A preliminary review of the gale data available for the earliest years was not very encouraging, and here the period is restricted to that for the years 1926–64, i.e. from the date of the establishment of a pressure-tube anemometer at Lerwick. A new electrical ‘in-line’ cup-generator distant-recording anemometer was installed in August 1961, in view of a rebuilding programme in the Observatory grounds. Comparison of the recordings of the two instruments for an overlap period of six months indicated no significant differences in the recorded speeds.

It was considered that trees might well react in the long run to sustained strong ‘blows’ more decisively than to the much shorter periods of winds severely restricted to the mean speeds of official gale force of 34 kt (38 m.p.h.) or more. This presentation is thus concerned with the analysis of monthly totals of the duration in hours of strong to gale winds (> 21 kt (24 m.p.h.)) as recorded at Lerwick Observatory and published in the *Monthly Weather Report*.

Decreased windiness in the last 15–20 years.—The variations of the durations of the strong to gale winds are shown in the seasonal histograms in

Figure 1. Additional interest is derived from aggregating the seasonal totals into yearly values. The annual period used is that from July to June as used by Hurst¹ to avoid splitting the winter seasons. The Lerwick annual totals for strong to gale winds are plotted in Figure 2.

The decrease in windiness at Lerwick since 1943 (July 1943 to June 1964) as compared with the previous 14 years or so is immediately obvious. A quiet period over the middle and late 1920's, particularly in spring, preceded the excessive activity of the mild stormy 1930's, culminating in the stormy period of later 1941 to 1943 in which the period from autumn 1942 through to the

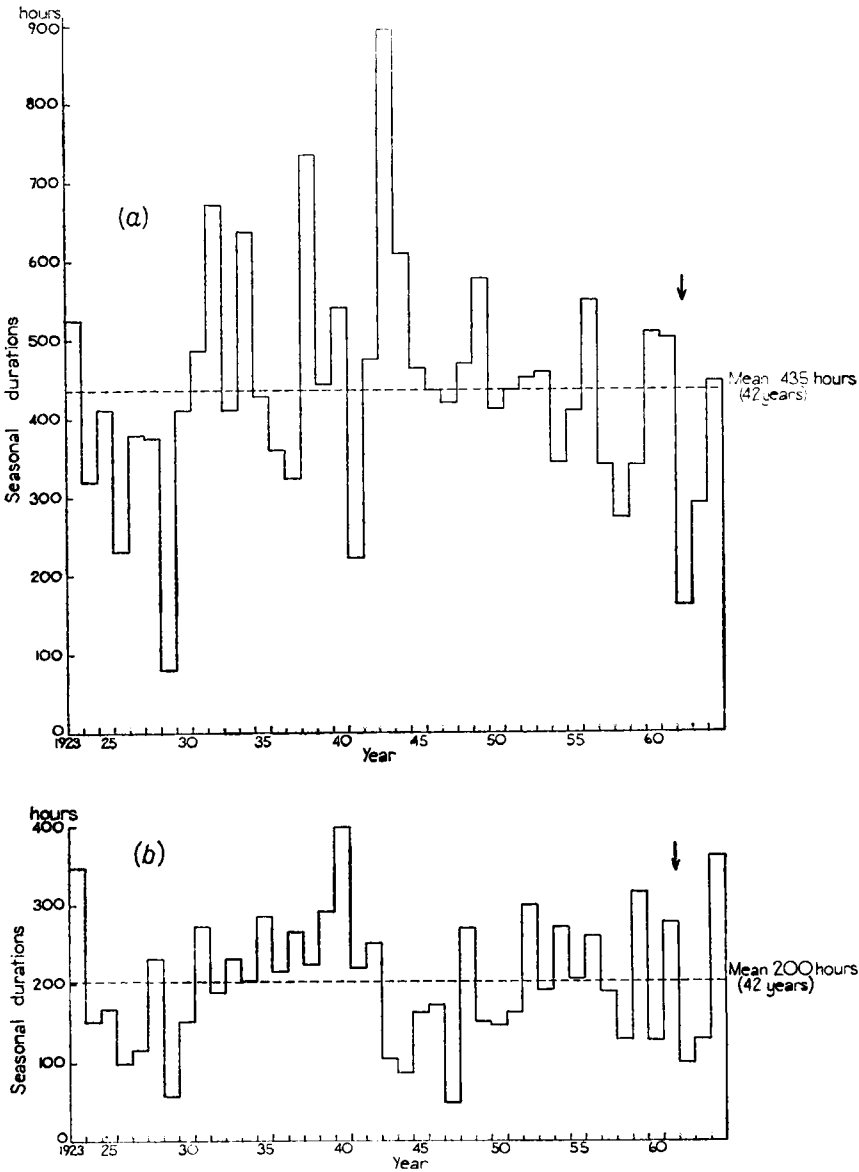


FIGURE 1—SEASONAL VARIATION OF DURATION IN HOURS OF WINDS EXCEEDING 21 KNOTS AT LERWICK, SHETLAND, 1923–64

(a) Spring (March–May); (b) Summer (June–August).

Bold arrows indicate the year in which a new anemometer was installed.

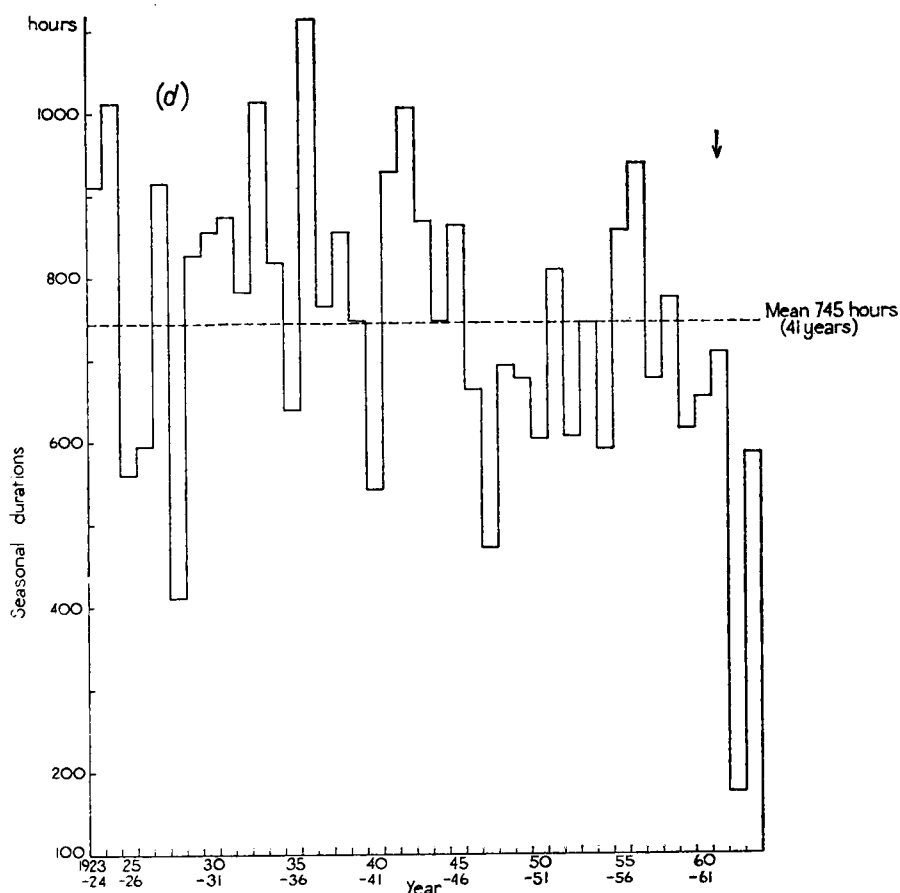
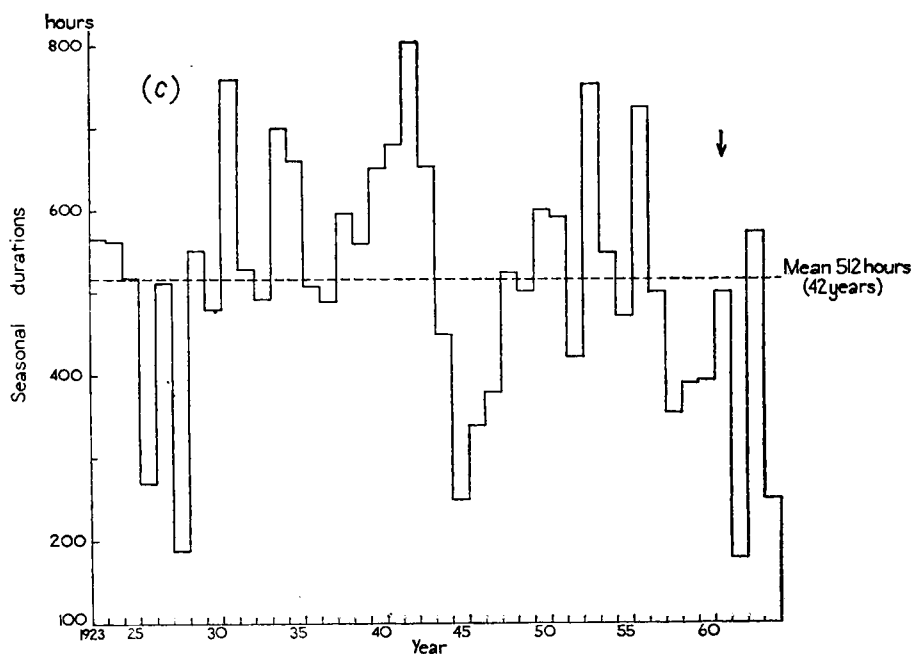


FIGURE I—SEASONAL VARIATION OF DURATION IN HOURS OF WINDS EXCEEDING 21 KNOTS AT LERWICK, SHETLAND, 1923–64—*contd*

(c) Autumn (September–November); (d) Winter (December–February).

Bold arrows indicate the year in which a new anemometer was installed. In years 1934–35, 39–40 and 43–44 in (d) one or two months were estimated.

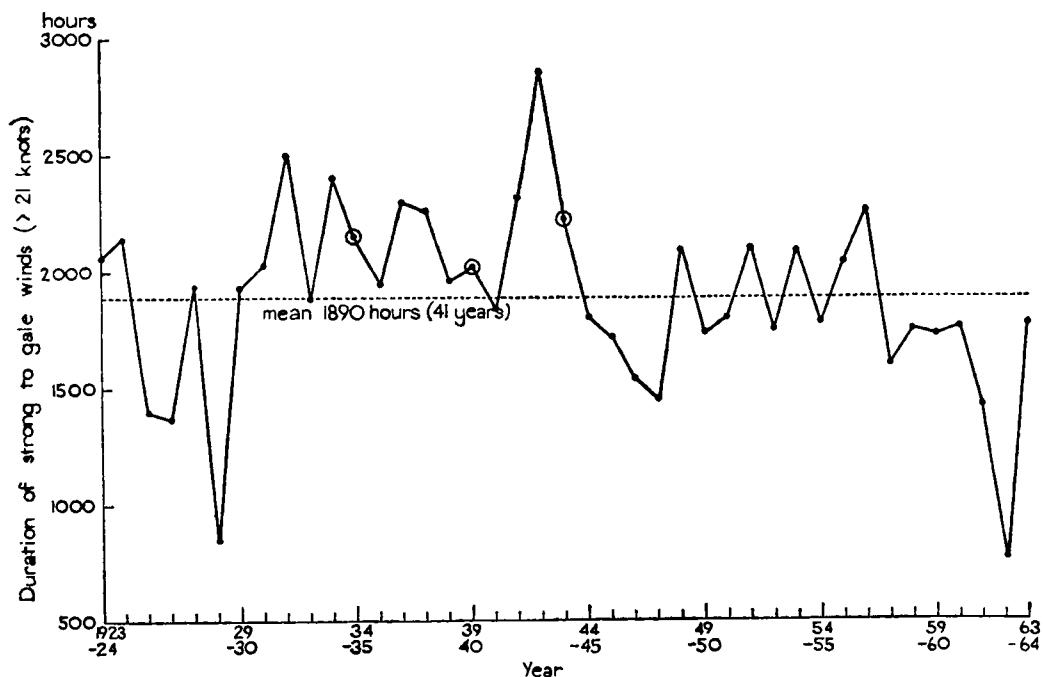


FIGURE 2—ANNUAL DURATION OF WINDS EXCEEDING 21 KNOTS AT LERWICK, SHETLAND, FOR YEARS (JULY-JUNE) 1923-24 TO 1963-64

Circled points indicate where one or two months were estimated.

spring of 1943 was characterized by outstanding activity. This was as if the winds decided to have a last vigorous fling before they were to be damped down by the climatic shift. Although 1956-57 was rather windy, the general vigour of the earlier years has not since been attained and the difference has been further emphasized by the quiet period 1944-47 and even more startlingly so by that from 1957 to the present date. The decreased windiness of the past 15 to 20 years is largely due to the increasing quiescence of the winter and spring quarters. Summers have, on the whole, not shown the same tendency and there have been some periods of autumnal vigour.

Comparison with other data.—Finally, the number of hours when the mean wind speed reached or exceeded gale force (34 kt or more) at Lerwick (Figure 3) were extracted to supplement similar data for Scilly, Valley, Stornoway and Mildenhall (1943-63) as given by Hurst.¹ The general overall rise in hours of gale at Stornoway and Scilly since 1956 is countered by a general and ultimately substantial decrease in the similar figures for Lerwick. The increased frequency of development and persistence of high pressure over the north polar area in recent years might reasonably be held to produce the difference between Lerwick and Scilly; that the effect is equally marked between Lerwick and Stornoway is surprising. Lamb² and Rodewald³ have shown that 'windiness' has increased south of Iceland and latterly more particularly near 50°N in the Atlantic at the same time as it has decreased in the Arctic (Spitsbergen, Greenland), and it would appear that Shetland also just falls within this extensive area of decreased windiness, with the Westman Islands (near Iceland) and Stornoway in the opposing camp. It would be interesting to have Hurst's analysis for earlier years.

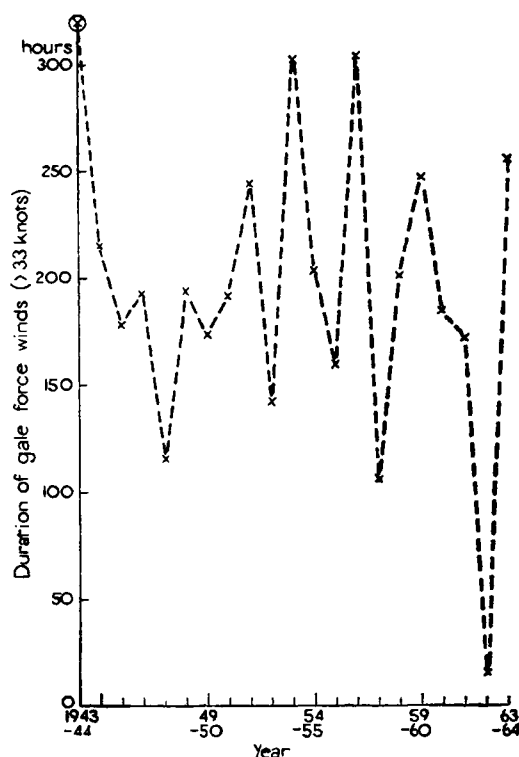


FIGURE 3—ANNUAL DURATIONS OF WINDS EXCEEDING 33 KNOTS (GALE FORCE) AT LERWICK, SHETLAND, FOR YEARS (JULY-JUNE) 1943-44 TO 1963-64
Circled point indicates where two months were estimated.

Apparent association with cold winters.—There appears to be a decrease in windiness at Lerwick before the onset of particularly cold winters in Scotland, leading to marked minima in windiness with or immediately after the hard weather. Thus five markedly quieter years as compared with previous years precede the extreme minimum of 1962-63; three quieter years precede the low value of 1928-29, and three precede the minimum of 1947-48. Thomson⁴ and McNaughton,⁵ in analyses of temperatures in the Edinburgh and Glasgow areas, list the winters of 1962-63, 1928-29 and 1946-47 as among the more severe Scottish winters. (Winter severity is related to the overall mean temperature for the three months December to February.)

A period of subnormal activity (1915-17) is also definitely indicated in the results obtained whilst endeavouring to find some comparable assessments of windiness for the period prior to the installation of the Lerwick anemometer. The winter of 1916-17 is 'cold' in the classifications.

Comparison with records from Orkney.—It is perhaps permissible in this article to draw attention to another aspect of windiness around northern Scotland. Over the earlier years a Robinson cup anemometer was in operation at Deerness, Orkney, until 1931. The first statistical approach however suggested that it might not be valid to accept the Orkney records as pertaining to Shetland. The point was further explored by making direct comparisons of the monthly durations of the prevalence of strong to gale winds for periods when anemometers were operating at both locations. A purely random choice of years was made to cover the moves and changes of the Orkney instrument to three

differing sites. The results showed conclusively that windiness in Orkney as indicated by anemographs at Deerness and Kirkwall (2 sites) was not by any means necessarily a near indication of windiness in Shetland. A complete lack of correspondence occurred much too frequently to engender any confidence in a long-period adaptation. The seasonal totals of hours of winds greater than 21 kt for the two locations are given in Table I, and adequately reflect the monthly differences. The figures provide a very salutary warning against the too facile assumption (without adequate backing from other considerations) that the windiness, as here defined and indicated by an anemometer at A is even a passable indication of windiness at B, barely 100 miles away in an area as remote and exposed as Orkney and Shetland.

TABLE I—SEASONAL TOTALS OF DURATIONS OF STRONG TO GALE WINDS IN SHETLAND AND ORKNEY FOR RANDOM YEARS COVERING SITE CHANGES IN ORKNEY

	1926		1927		1941		1942		1958		1959		1962		1963	
	S	DO	S	DO	S	KO	S	KO	S	GO	S	GO	S	GO	S	GO
	hours															
Spring	232	230	381	240	223	169	477	361	274	257	341	138	163	259	292	331
Summer	98	86	115	79	220	26	251	70	129	30	316	132	100	221	131	36
Autumn	269	195	512	273	679	444	804	290	354	120	391	244	178	251	575	314
Winter	1926-27		1927-28		1941-42		1942-43		1958-59		1959-60		1962-63			
	598	421	916	616	930	557	1007	493	755	333	615	488	177	293	588	375

S=Shetland; DO=Deerness, Orkney; KO=Kirkwall, Orkney; GO=Grimsetter, Orkney.

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HEAVY THUNDERSTORM WITH HAIL AT KUCHING (SARAWAK)

By A. STEMMLER and P. M. STEPHENSON

Introduction.—On 22 September 1964 a heavy thunderstorm with hail occurred at about 1525 hours local time (0725 GMT) at Kuching Airport (01°29'N, 110°21'E; 84 feet above MSL). The rainfall associated with the storm (about 2½ inches in one place) was not exceptional for equatorial regions but the precipitation of hail at a location within 2 degrees of the equator and less than 100 feet above sea level is considered noteworthy and before the storm is discussed in detail a brief review of earlier references to the occurrence of hail near the equator is made.

Equatorial hail.—There is rather a dearth of literature on hail in the tropics, which is perhaps indicative of its infrequent occurrence. An early reference by

Humphreys¹ states baldly "In the tropics, where the freezing level is very high, hail seldom occurs". Lemons²—"Hailstorms are infrequent in very low latitudes"—is equally summary in his approach but he does concede that "the records of various United States Weather Bureau stations located in low latitudes show greater frequency and destructiveness of hailstorms at high altitudes than at low ones", quoting in support Selga who, writing on "Hail in the Philippines" in 1929, concluded that 'the frequency is greatest in the central highlands but occurs occasionally in the lowlands'. Lemons also reports 10 instances of low-level hail in a 10-year period in northern Australia within 12 to 16 degrees of the equator.

Turning to textbooks on tropical meteorology we find Garbell³ stating that "generally speaking, the frequency of hail in low latitudes is less than that observed in middle latitudes. . . In continental areas and especially in mountainous terrain, however, violent intertropical-front hailstorms are frequent, even in the lowest latitudes". Riehl,⁴ on the other hand, makes little reference to the relative frequencies of occurrence of hail.

In more recent literature on the subject, Sansom,⁵ writing about British East Africa, says "The relationship between the frequency of occurrence of hail and the altitude is not simple. . . No occurrences of hail have been reported at the Coast, nor at many places between sea level and 1200 m, but the District Agricultural Officer, Kwale, reports that hailstorms occur every year in a small area round Makamini at an altitude of only 150 m or so, and only about 56 km from Mombasa. . . It is, however, apparent that the optimum altitude for hailstorms lies between 1500 and 2750 m, and that below 1100 m hailstorms are rare".

The writers so far quoted agree on the rarity of low-level hailstorms close to the equator but concede that hail might be encountered more frequently at higher altitudes, thus lending support to the widely held theory that if hail were present in cumulonimbus cloud in the tropics it would melt before reaching sea level because of the high altitude of the 0°C level (about 15,000 feet near the equator). Ludlam,⁶ however, doubts this explanation on the grounds of the prevalence of very severe hailstorms in India and his own work showing that "the diameter of large stones can be only slightly diminished by melting during fall, although those of diameter less than about 1½ cm may melt completely". He argues that "in tropical regions the wind shear in the lower troposphere which is favourable for the development of the severe storm does not persist into the high troposphere, in contrast to the behaviour in middle latitudes. . . The small hailstone embryos which fall from the anvil mostly enter the downdraft rather than re-enter the updraft, and so can be considered to be denied the opportunity of a second ascent in which to complete their growth into large stones". Against this argument, however, must be placed (a) the work of Fawbush and Miller⁷ who found a definite relationship between the height of the wet-bulb freezing-level above the ground and the frequency of occurrence and size of hail reported at the surface and (b) that of Sansom who says (communicated) that strong vertical wind shear is "a factor not necessarily (or even usually) associated with the western Kenya hailstorms, but typical of the severe travelling storm which leaves a hail swath over quite a considerable distance".

Turning to the Malaysian area, an inspection has been made of 10 years' records⁸ of some 20 stations in the regions, including Fraser's Hill (4268 feet above MSL), which reveals not one reported occurrence of hail in Malaya,

Singapore or North Borneo. Moreover, aircraft flying in the area rarely report hail in cumulonimbus cloud, even when looking for it (see Frost⁹ for example).

Summarizing, although hail occurs fairly frequently in tropical regions away from the equator and occasionally over high ground near the equator, it appears to have been very rarely recorded at low levels near the equator. Neither of the suggested explanations (high 0°C level and absence of suitable wind shear) seems entirely satisfactory and it may be that the true explanation involves both these factors, along with others. For example, if the upper-wind configuration inhibited the growth of hailstones to the extent that only small stones (less than 1½-cm diameter) were formed, these would be expected to melt before reaching the ground. Frost⁹ further propounds the argument that the rapid glaciation of a tropical cumulonimbus cloud in its later stages of development inhibits the growth of hailstones by substantially reducing the liquid water content of the cloud.

The Kuching storm.—Kuching is the capital of Sarawak in Malaysian Borneo, the airfield being about 6 miles south of the town (Figure 1). Some 40

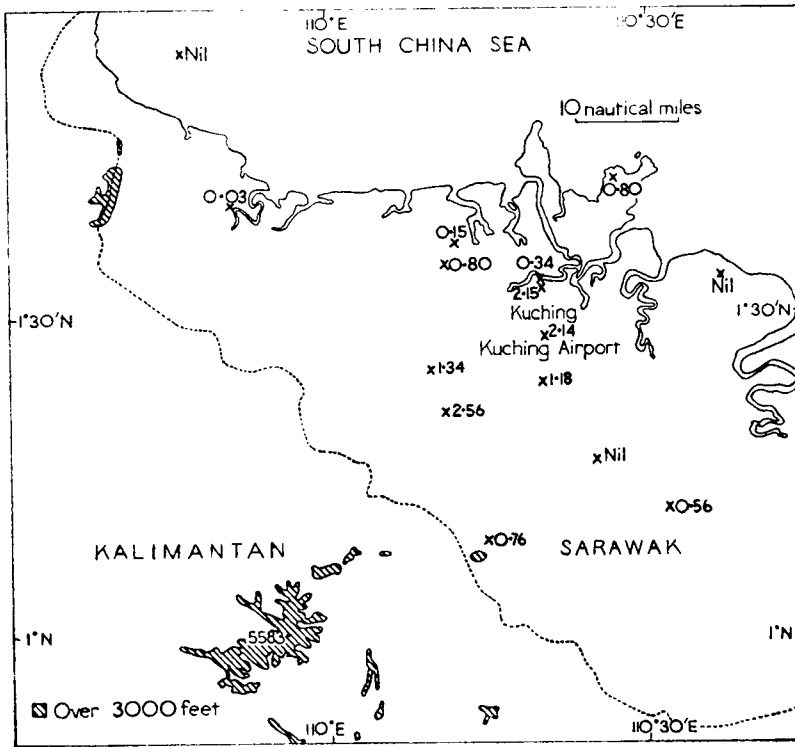


FIGURE 1—REPORTS OF RAINFALL ON 22 SEPTEMBER, THE DAY OF THE STORM AT KUCHING

X Reports of rainfall (midnight to midnight on 22nd) in inches.

miles to the south and south-west is a mountainous region with peaks of over 5000 feet, whilst to the north-west, west and south-south-east there are only isolate knolls. To the north, north-east, east and south-east the ground is mainly swampy.

The few days prior to the occurrence of the storm had been hot and mainly dry with little or no rain. The local farmers were burning the undergrowth

and secondary jungle in preparation for the planting of paddy, this being the normal practice before the Landas season (north-east monsoon) arrives with its marked increase in rainfall. On the day of the storm two large fires were observed at about 1440 hours local time, one about 10 miles to the south-west and the other 5 to 10 miles to the west-north-west of the airfield. Both were producing large masses of thick black smoke, rising almost vertically in the fairly light low-level winds (10 knots or less up to 7000 feet).

The normal development of cumulus mediocris was taking place, one or two of the clouds producing radar echoes. A single cumulus congestus cloud was forming towards the high ground to the south-west of the airfield and moving north-eastwards in the prevailing low-level south-west flow. As the cloud reached the rising smoke a marked increase in its vertical development was noted and the beginning of anvil formation was observed as the cloud started to glaciate at about 1450 hours local time. The general base of the cumulus cloud was estimated to be 4000 to 5000 feet; this was supported by later aircraft reports. The general tops were estimated at 15,000 to 20,000 feet with the top of the large cloud at 25,000 to 30,000 feet. Radar reports suggested that the diameter of this particular cloud was about 25 miles and its movement towards east-north-east at 10 knots.

At 1505 hours the wind recorded on the pressure-tube anemograph, having been fairly steady at 080° 05 knots, became 160° 16 knots with gusts to 25 knots. The anemograph is situated at the southern end of the airfield close to buildings but is at a height of 40 feet above the ground and 32 feet above the nearby buildings. The temperature as recorded by the thermograph in the thermometer screen was 92°F and the relative humidity was steady at about 58 per cent. Although it was not raining at the airfield at this time, a shower was observed to the south-west within 5 miles. Small eddies of sand and dust were apparent on the domestic site to the south-east of the airfield where the terrain consists mainly of loose sand.

At 1515 hours heavy rain commenced at the airfield and visibility fell to about 500 yards. Ten minutes later the precipitation turned to hail, which lasted about half a minute. Mr. Benedict Chin, the Meteorological Supervisor of the Sarawak Department of Civil Aviation, picked up some of the hail which melted very rapidly. It was estimated to be about $\frac{3}{8}$ inches in diameter and was composed almost entirely of clear ice. At 1525 hours the wind veered to 180° 36 knots with a single gust of 61 knots. (The previous highest gust since 1954 when records commenced was $49\cdot8$ knots on 25 November 1958.) The temperature fell to 71°F and the relative humidity rose rapidly to 96 per cent. By 1530 hours the wind had fallen to 4 knots with variable direction, the intensity of the rain had lessened considerably and by 1555 hours it had ceased; the visibility improved rapidly to 10–15 nautical miles. During the 40 minutes of rain $1\cdot36$ inches had fallen, during a 30-minute period $1\cdot24$ inches had fallen and during a 20-minute period $1\cdot00$ inches had fallen. (The highest rainfall recorded in any hour in Singapore, for comparison, was $4\cdot98$ inches on 20 April 1953.) The 24-hour rainfall (0000 to 2400 GMT) for 22 September was $2\cdot14$ inches at Kuching Airport. The corresponding 24-hour rainfall totals for a number of other stations are plotted on Figure 1 and indicate the extremely local nature of the storm and the path along which it appeared to travel. The radar echoes at 1610 hours suggested that the storm was splitting into two but the main area was moving away from the station towards east-north-east.

The only reported damage in the Kuching area was at or near the airfield. At the height of the storm a Valetta aircraft was moved through 160° and a single-engined Pioneer broke away from its mooring ropes. Neither aircraft was damaged but one or two temporary wooden huts near the airfield were demolished.

Lack of data precludes detailed discussion of the possible reasons for this almost unprecedented fall of hail. The nearest radiosonde station is at Paya Lebar (Singapore), about 450 miles from Kuching and the ascent for 0800 hours local time gives the true height of the wet-bulb and dry-bulb 0°C levels as 13,500 feet and 16,000 feet respectively, both close to their normal values. In the Fawbush and Miller⁷ investigation of 274 cases of hail reaching the ground, on only one occasion was the wet-bulb 0°C level as high as 13,500 feet and the diameter of the hail on that occasion was $\frac{1}{4}$ inch. The upper-wind ascents at Kuching are made using pilot balloons and at 0800 hours and 1400 hours local time on the day of the storm, winds were measured to heights of only about 10,000 feet. The 3000-foot and 10,000-foot winds at Kuching on 22 September 1964 were as follows:

Local time	0800	1400
3000 feet	180° 9 knots	160° 10 knots
10,000 feet	250° 17 knots	not reached

In this case Ludlam's⁶ model favouring the formation of hail would require increasing westerly winds with height above 10,000 feet, but the Paya Lebar ascent shows the normal reversion to easterly winds above 450 mb. However, in the absence of detailed aerological data to high levels above Kuching itself it is impossible to reach any definite conclusions about cause and effect. The one abnormal feature of the situation was that the storm appeared to have been intensified by the presence of rising smoke from the jungle fire. A similar instance was reported by McAllen¹⁰ but no information as to the presence or otherwise of hail was available on that occasion.

In conclusion it is interesting to speculate as to whether this occurrence of hail at a low altitude close to the equator was in fact as unique as the evidence appears to indicate. Rainfall in equatorial storms is often so heavy that the presence of hail could go undetected, both aurally and visually, and it may be that in this case only the presence of an alert observer in the right place and at the right time resulted in its being reported.

Acknowledgement.—The observational data for the Kuching area were supplied by courtesy of the Meteorological Office, Sarawak Department of Civil Aviation.

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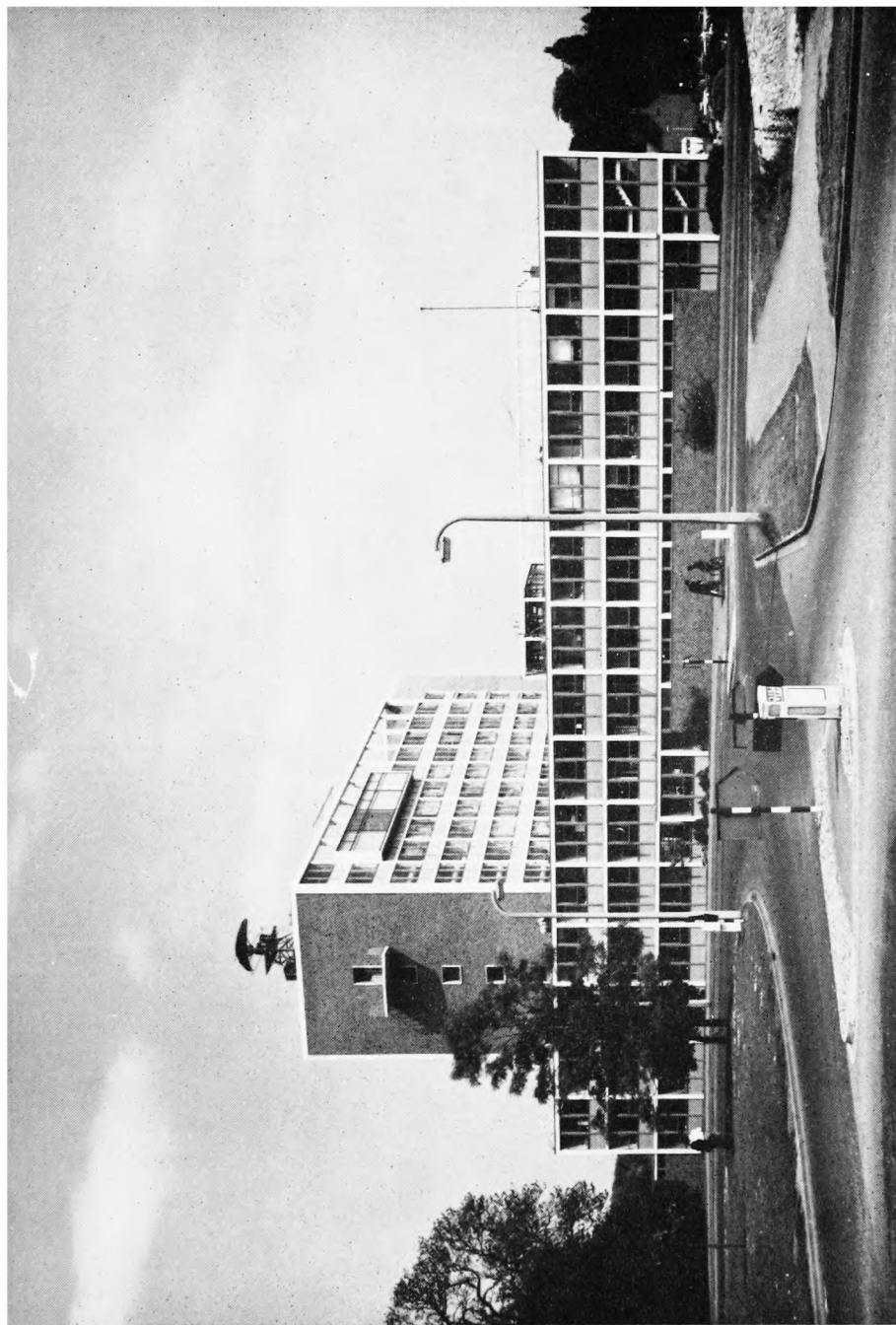
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PLATE I—UPPER AIR TEMPERATURES FROM A ROCKET SONDE

R. Almond and Dr. R. Frith are extracting significant data from the temperature recording obtained from a rocket sonde as it makes its parachute descent from 70 kilometres after being fired to this height by the SKUA meteorological rocket.



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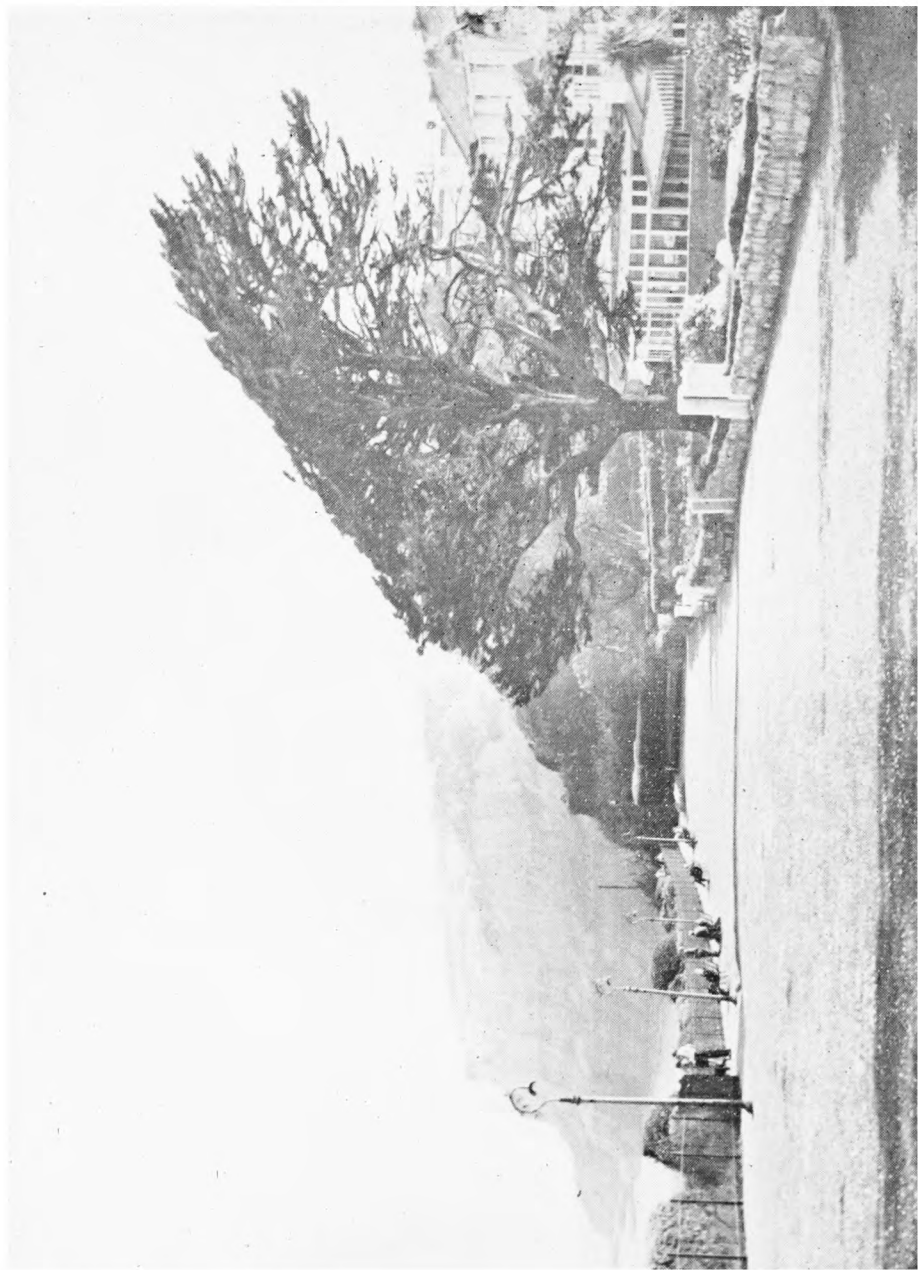
PLATE II—METEOROLOGICAL OFFICE HEADQUARTERS AT BRACKNELL

A weather radar aerial was installed on the roof in May 1965 and trials commenced in July.



Photograph by Margaret M. Woods

PLATE III—INSTALLING THE WEATHER RADAR AERIAL AT BRACKNELL
The display tube is in a room adjacent to the forecast room.



Photograph by G. Nicholson

PLATE IV—TREE ON THE CLIFF EDGE TO THE SOUTH-WEST OF SHANKLIN ON THE ISLE OF WIGHT

The tree has been shaped by exposure to the prevailing wind.

FORECASTING DRY SPELLS OF THREE DAYS OR MORE IN SOUTH-EAST ENGLAND FROM MAY TO OCTOBER: A REVISED MODEL

By C. A. S. LOWNDES

Introduction.—In an earlier paper¹ the synoptic types associated with dry spells at London for the months May to October were classified into Types I to IX and rules were described² for forecasting dry spells at London and in south-east England associated with a spread of high pressure from the south-west of the British Isles, classified as Type V. The basic predictors were a mobile upper trough between 60°W and 50°W and surface pressure above normal at the Azores. From a study of the dry spells of 1964, it seemed likely that the surface pressure at the Azores was not a sufficiently precise predictor and that better results would be obtained by using the position and central pressure of the surface high in the Azores region, as used in the model derived for forecasting Type V dry spells in the winter months.³

Data extracted.—For the 16 years 1949 to 1964, all occasions when a 500 millibar trough was situated between 60°W and 50°W were noted and the following data extracted. All upper air data were obtained from 500 mb charts.

(i) *Upper air data*

(a) The maximum negative (or minimum positive) height anomaly at 45°N on the trough axis between 60°W and 50°W.

(b) The latitude of the centre of the belt of flow around the base of the trough.

(c) The latitude at which the flow on the eastern flank of the trough changed from a point west of south to a point east of south (if applicable).

(d) The spacing from the trough between 60°W and 50°W to the next upwind trough.

(e) The 500 mb height at Lajes (Azores) minus that at Keflavik (Iceland) (a measure of the 'zonal index').

To obtain the 500 mb height anomaly on the trough axis, 5-day mean values of 500 mb height at latitude 45°N for longitudes 60°W and 50°W were used. These were based on 5-year monthly means for the period 1949 to 1953 published by Berlin University.⁴

(ii) *Surface data*

(a) The position and central pressure of all surface highs with a central pressure of 1020 mb or more in the Atlantic-European sector between longitudes 50°W and 50°E and from latitudes 30°N to 70°N. (The central pressure of the high was taken to be that of the closed isobar nearest the centre with isobars at 4 mb intervals.)

(b) The dates of the beginning and end of all dry spells of three days or more in south-east England. A dry spell was defined as a period when none of a group of 11 stations in south-east England, for which 12-hour totals of precipitation are given in the *Daily Weather Report*, had more than a trace of precipitation. The 6 stations, Kew, London (Heathrow) Airport, Gorleston, Mildenhall, West Raynham and Boscombe Down were available throughout the 16-year

period. The other 5 varied but came from the following group of 10 stations: Thorney Island, Hurn, Lympne, Tangmere, Calshot, Cranfield, London (Gatwick) Airport, Felixstowe, Cardington and Wittering. On a few occasions, when it was clearly illogical to split a dry spell, a small amount of precipitation over a short period was allowed. This usually involved up to 0.2 millimetres provided by moist airstreams from the sea affecting coastal stations or by wet fog at night.

The critical values of the predictors.—A study was made of occasions when a 500 mb trough was situated between 60°W and 50°W and at the same time a surface high was situated between longitudes 50°W and 5°W and latitudes 30°N and 60°N (see Figure 4).

The intensity of the trough between 60°W and 50°W.—The intensity of the trough between 60°W and 50°W was not critical. Dry spells which began within two days were associated with troughs with contour anomalies at 45°N ranging from -30 to +5 decametres. However, some very flat troughs were not associated with dry spells. On these occasions, the flow around the base of the trough was centred north of 51°N. On nearly all occasions when a dry spell followed, the flow was centred south of 52°N.

The flow on the eastern flank of the trough.—The flow ahead of troughs which were associated with dry spells was usually south-westerly or south-south-westerly. On occasions when the flow changed from a point west of south to a point east of south, south of latitude 57°N, no dry spell followed. An example of this type of trough is shown in Figure 1. The 500 mb chart for 0300 GMT on 4 October 1956 shows the flow ahead of the trough changing from a point west of south to a point east of south at 48°N. On this occasion a surface high developed near Iceland and linked with the high to the south-west of the British Isles. The resulting high which was elongated north-south to the west of the British Isles brought cyclonic northerlies across south-east England.

The spacing to the next upwind trough.—On occasions when a dry spell followed within two days, the spacing from the trough between 60°W and 50°W to the next upwind trough was on nearly all occasions 32° or more. On a number of occasions when no dry spell followed, the spacing was less than 32°. An example of this type of situation is shown in Figure 2. The 500 mb chart for 1500 GMT on 22 September 1950 shows the trough between 60°W and 50°W followed by another trough less than 32° upwind. During the following 48 hours, the trough between 60°W and 50°W ran forward quickly as a weak feature whilst a major trough formed at 70°W. The surface high to the south-west of the British Isles moved to France and weakened, allowing a depression from the Atlantic to move across the British Isles.

The zonal flow across the Atlantic ('zonal index').—A measure of the zonal flow across the Atlantic when the trough was situated between 60°W and 50°W was found to be a useful predictor. The index used was the 500 mb height at Lajes in the Azores minus that at Keflavik in Iceland. On nearly all occasions when a dry spell occurred, the zonal index defined in this way was less than 60 decametres. On occasions when the index was above 60, the surface high to the south-west often moved rapidly eastwards south of the British Isles or extended a ridge over France or Spain, with cyclonic westerlies bringing rain to the British Isles.

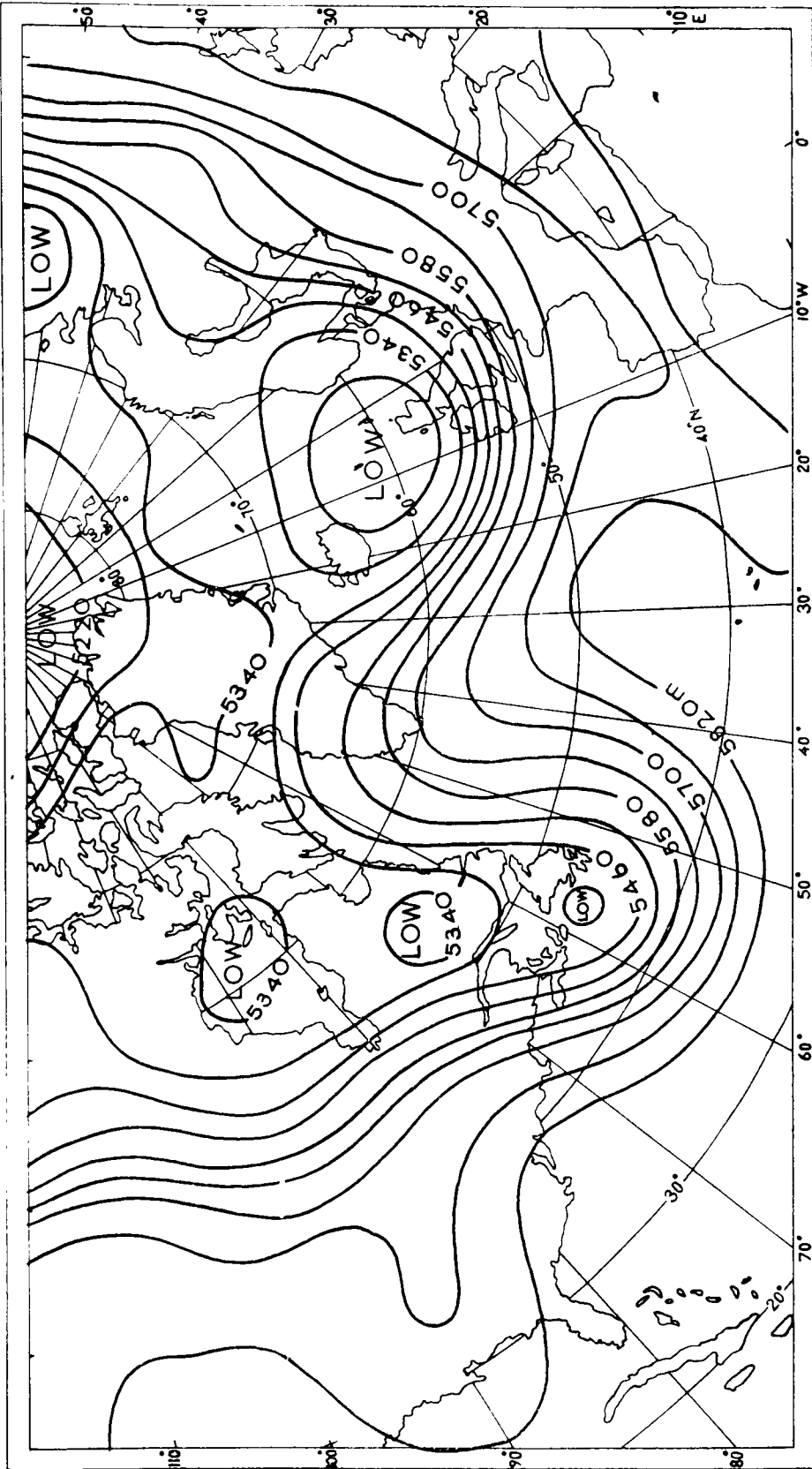


FIGURE 1—THE FLOW ON THE EASTERN FLANK OF THE TROUGH—A CRITERION FOR A DRY SPELL NOT SATISFIED
500 mb contours at 0300 GMT on 4 October 1956.

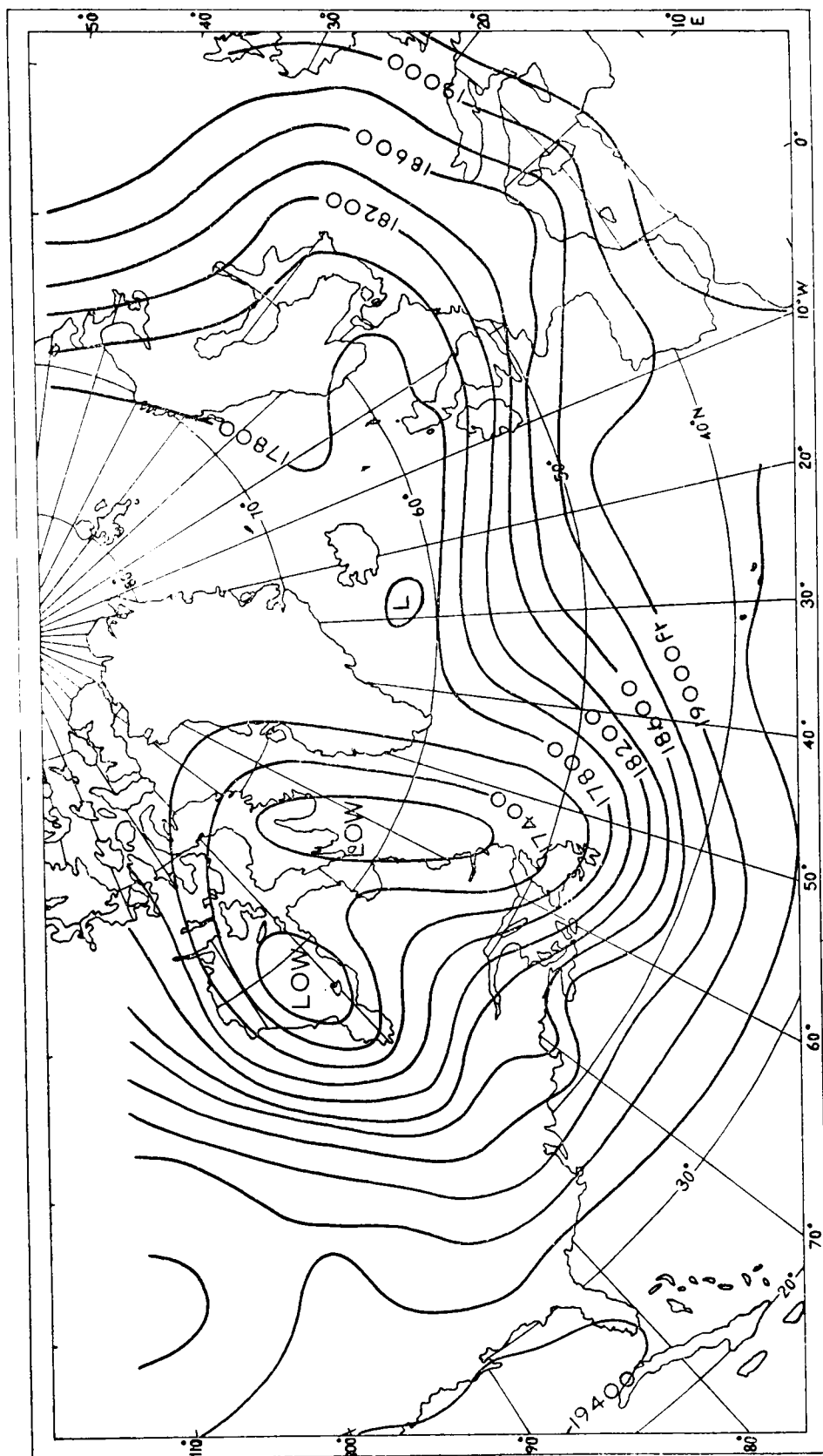


FIGURE 2—THE SPACING TO THE NEXT UPWIND TROUGH—A CRITERION FOR A DRY SPELL NOT SATISFIED
500 mb contours (feet) at 1500 GMT on 22 September 1950.

The orientation of the surface high.—On a number of occasions when other factors were favourable and no dry spell occurred, the surface high to the south-west of the British Isles was elongated in a northerly direction towards Iceland or Greenland.

Surface highs in the region of Iceland.—On some occasions when no dry spell occurred, a second surface high was situated in the Iceland region. Figure 3 shows the position and central pressure of surface highs in the Iceland region when other factors were suitable for a dry spell. If a dry spell of three days or more began within two days, a dot was plotted and a dry spell of two days was indicated by a dot within a circle. If no dry spell began within two days, a cross was plotted. It is clear that a dry spell is unlikely if a high of 1016 mb or more is situated within the specified area.

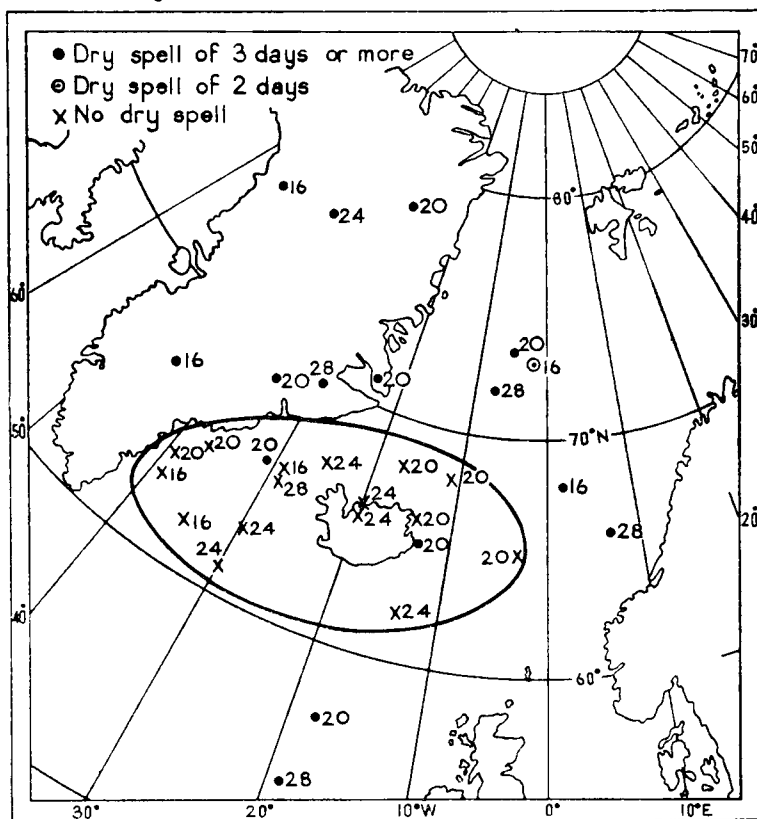


FIGURE 3—POSITION AND INTENSITY OF SURFACE HIGHS IN THE ICELAND REGION
The central pressures of the surface highs are given in millibars omitting the first two figures.

A summary of the critical values of the predictors.—The critical values of the predictors were as follows:

- (i) The flow around the base of the trough between 60°W and 50°W must be centred south of 52°N.
- (ii) The flow ahead of the trough must not be from a point east of south, south of latitude 57°N.
- (iii) The spacing to the next upwind trough must not be less than 32° of longitude.
- (iv) The 'zonal index' must be less than 60 decametres.

(v) The surface high must not be elongated in a northerly direction towards Iceland or Greenland.

(vi) A second surface high with a central pressure of 1016 mb or more must not be situated in the specified area near Iceland.

Including only those occasions when the above conditions were satisfied, a diagram was plotted (Figure 4) showing the positions of surface highs with a central pressure of 1024 mb or more. Highs with a central pressure of 1020 mb were not included because it had become clear that none were associated with dry spells. An area enclosing many of the dry-spell plots is shown to the south-west of the British Isles. Within the area the central pressure of the highs which were associated with dry spells of three days or more ranged from 1024 to 1036 mb. Of the 70 dry spells of three days or more associated with the highs

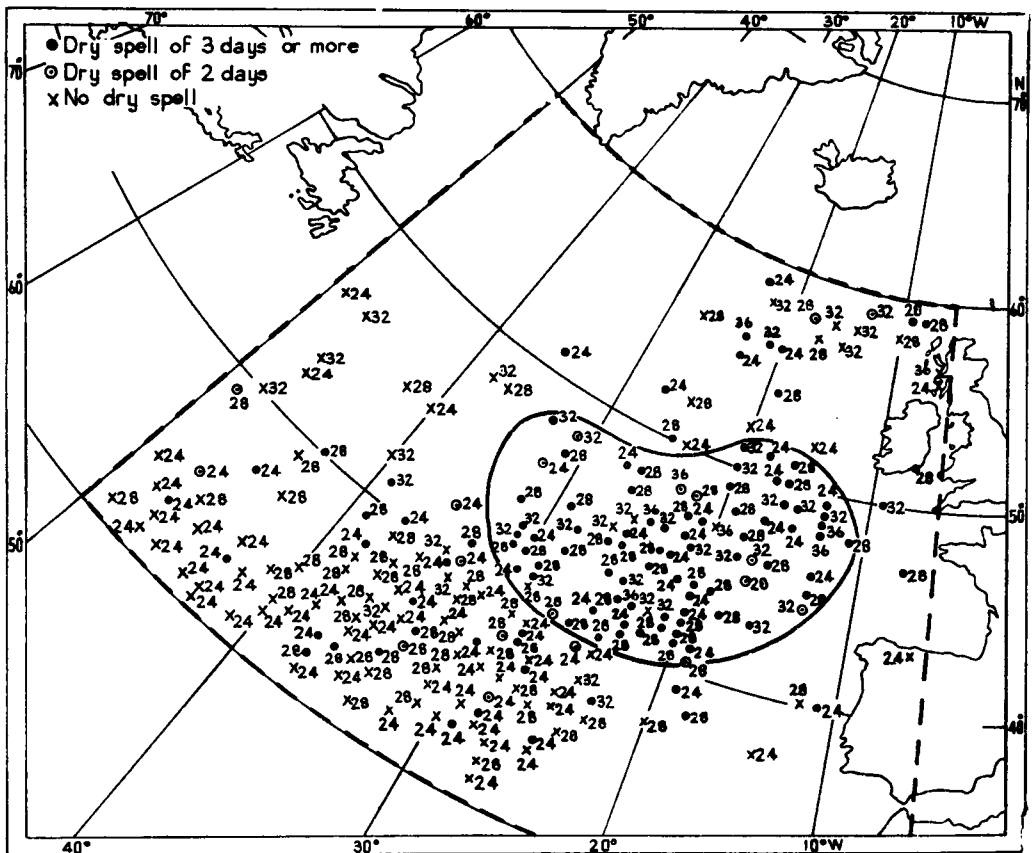


FIGURE 4—REVISED MODEL: POSITION AND INTENSITY OF SURFACE HIGHS

The central pressures of the surface highs are given in millibars omitting the first two figures.

within the area, 18 began on the same day that the trough reached longitudes 60°W to 50°W, 24 began one day later and 11 began two days later. Some 17 spells had already started and continued for a further three days. All of the spells which began on the same day or which had already started were of sufficient duration for a forecast of at least three days dry weather to be feasible. Five highs were associated with the continuation for a further three days of spells the beginning of which had already been forecast. On 8 occasions a high within the area was associated with a dry spell of two days and on 5 occasions no dry spell occurred.

The tracks taken by the surface highs.—Figure 5 shows, for the years 1949 to 1959, the tracks taken by the surface highs from their initial positions within the specified area to their positions three days later for occasions when there was no other high in the Atlantic–European sector. The highs generally moved in a north-easterly direction towards, over or to the south of the British Isles. After three days most of the highs were positioned south-west, south or south-east of the British Isles.

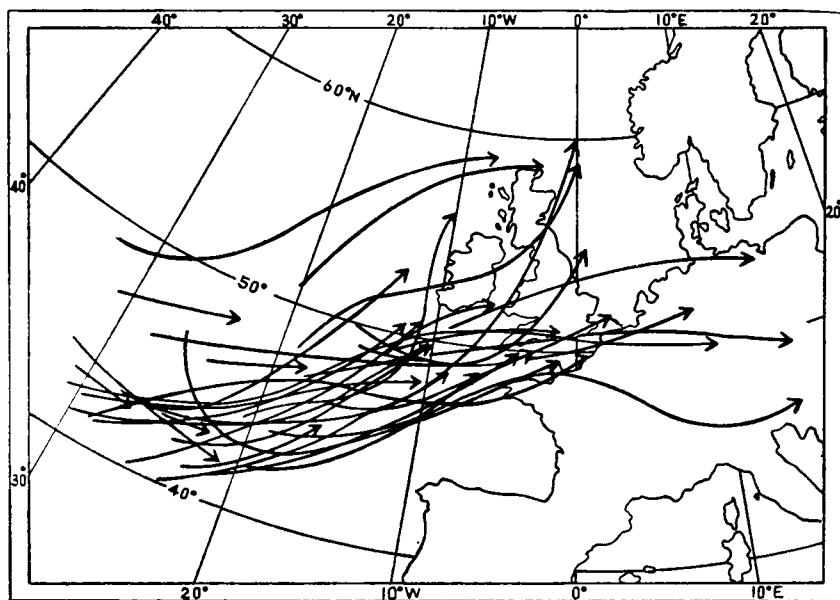


FIGURE 5—REVISED MODEL: TRACKS OF SURFACE HIGHS OVER THREE DAYS

The effect of a second surface high in the Atlantic–European sector.—A study was made of the effect of a second surface high in the Atlantic–European sector. On 45 of the 75 occasions associated with dry spells of three days or more, there was no other surface high with a central pressure of 1024 mb or more in the Atlantic–European sector. On 11 occasions another high was situated over Russia or Poland, on 8 occasions to the west or south-west of the Azores, on 3 occasions to the west of the British Isles and on one occasion over Scandinavia, Denmark, the North Sea, north of the British Isles, over Biscay, over mid-Atlantic, south of the Azores and over the Azores. The high to the south-west of the British Isles lost its identity by linking with the other high on only 9 of the 30 occasions. Of these 9 highs, 3 were situated to the west of the British Isles and one each over Russia, Scandinavia, Denmark, to the north of the British Isles, over Biscay and to the south-west of the Azores.

Rules for forecasting dry spells in south-east England from May to October.—

- (i) Take note of each chart on which a 500 mb trough is situated between 60°W and 50°W.
- (ii) If a surface high with a central pressure of 1024 mb or more is situated within the specified area to the south-west of the British Isles (see Figure 4) a dry spell is likely to begin in south-east England within one or two days. Sometimes the dry spell may have begun already and a continuation for a further three days is likely.

This procedure applies provided that (a) the flow around the base of the trough is centred south of 52°N , (b) the flow ahead of the trough is not from a point east of south in a latitude south of 57°N , (c) the spacing to the next upwind trough is not less than 32° of longitude, (d) the 'zonal index' is less than 60 decametres, (e) the surface high is not elongated in a northerly direction towards Iceland or Greenland and (f) another high of 1016 mb or more is not situated in the region of Iceland (see Figure 3). Another high may be situated in any other part of the Atlantic-European sector.

An occasion when the criteria were obeyed and a dry spell followed.

—An interesting example of the model occurred in June 1959. The 500 mb chart for 1200 GMT on 9 June 1959 (Figure 6) shows a trough at 53°W with the flow around the base of the trough centred at about 45°N . The flow ahead of the trough was from a point west of south and did not become east of south in any latitude. The spacing to the next upwind trough was clearly not less than 32° of longitude. The 'zonal index' was 52 decametres.

The corresponding surface chart (Figure 7) shows a high with a central pressure of 1036 mb centred at $42^{\circ}\text{N } 23^{\circ}\text{W}$, within the specified area to the south-west of the British Isles. The high was not elongated in a northerly direction towards Iceland or Greenland and there was no high in the region of Iceland. The criteria for a dry spell were thus clearly obeyed and a dry period began in south-east England by 2100 GMT on the 9th. Apart from up to 0.2 mm at one or two stations on the 12th, it continued dry until 21 June.

The 500 mb trough moved eastwards, reaching 40°W by the 11th, then weakened rapidly. The surface high moved to the South-West Approaches by the 11th and to the British Isles by the 12th, the central pressure having fallen slightly to 1032 mb.

The proportion of dry spells forecast.—Table I shows the number of spells of three days or more which actually occurred during the period 1949 to 1964 with figures in brackets indicating the number which would have been forecast.

TABLE I—THE NUMBER OF DRY SPELLS WHICH OCCURRED AND THE NUMBER FORECAST (1949–64)

Synoptic type	I(NE)	II(E)	III(SE)	IV(S)	V(SW)	VI(W)	VII(NW)	VIII(N)	Total
	<i>number of spells</i>								
May	2(0)	1(0)	1(0)	3(0)	6(6)	4(0)	2(0)	5(1)	24(7)
June	1(0)	1(0)	—	2(0)	11(9)	7(2)	1(0)	1(0)	24(11)
July	—	—	—	2(0)	19(16)	5(0)	—	—	26(16)
August	1(0)	—	2(0)	1(0)	11(11)	4(2)	—	—	19(13)
September	2(0)	1(0)	—	3(0)	12(11)	6(1)	1(0)	—	25(12)
October	1(0)	1(0)	—	5(0)	11(11)	1(0)	—	—	19(11)
Total	7(0)	4(0)	3(0)	16(0)	70(64)	27(5)	4(0)	6(1)	137(70)

Figures in brackets indicate the number of spells which would have been forecast.

The rules would have forecast 64 of the 70 Type V spells of three days or more which actually occurred, 5 of the 27 Type VI spells and one of the Type VIII spells. Of the 137 spells of all types 70 would have been forecast. The rules would also have forecast 8 dry spells of two days duration and on 5 occasions the forecast of a dry spell would have failed. Table II shows the number of spells of three days or more which actually occurred in each individual year with figures in brackets indicating the number which would have been forecast.

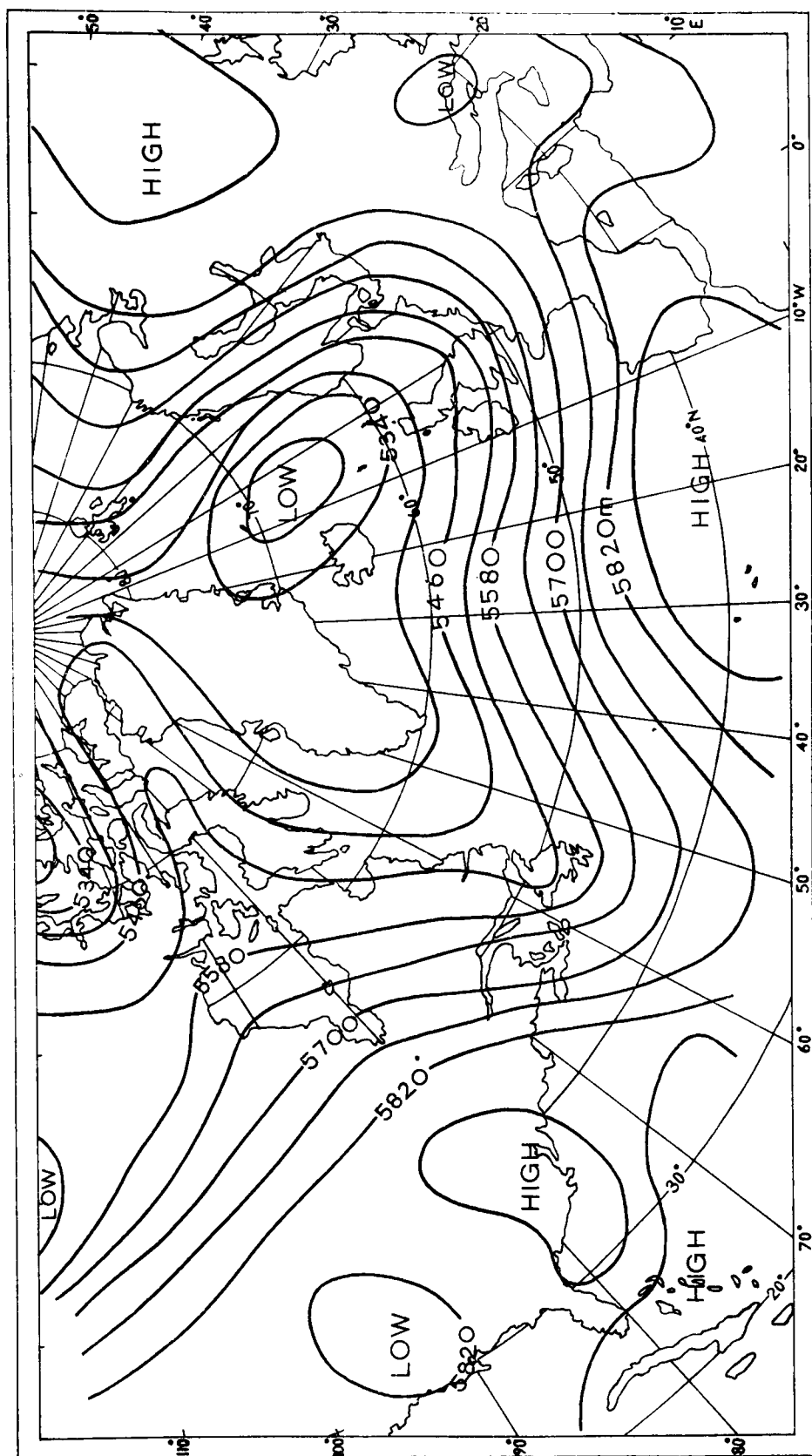


FIGURE 6—CRITERIA FOR A DRY SPELL SATISFIED

500 mb contours for 1200 GMT on 9 June 1959.

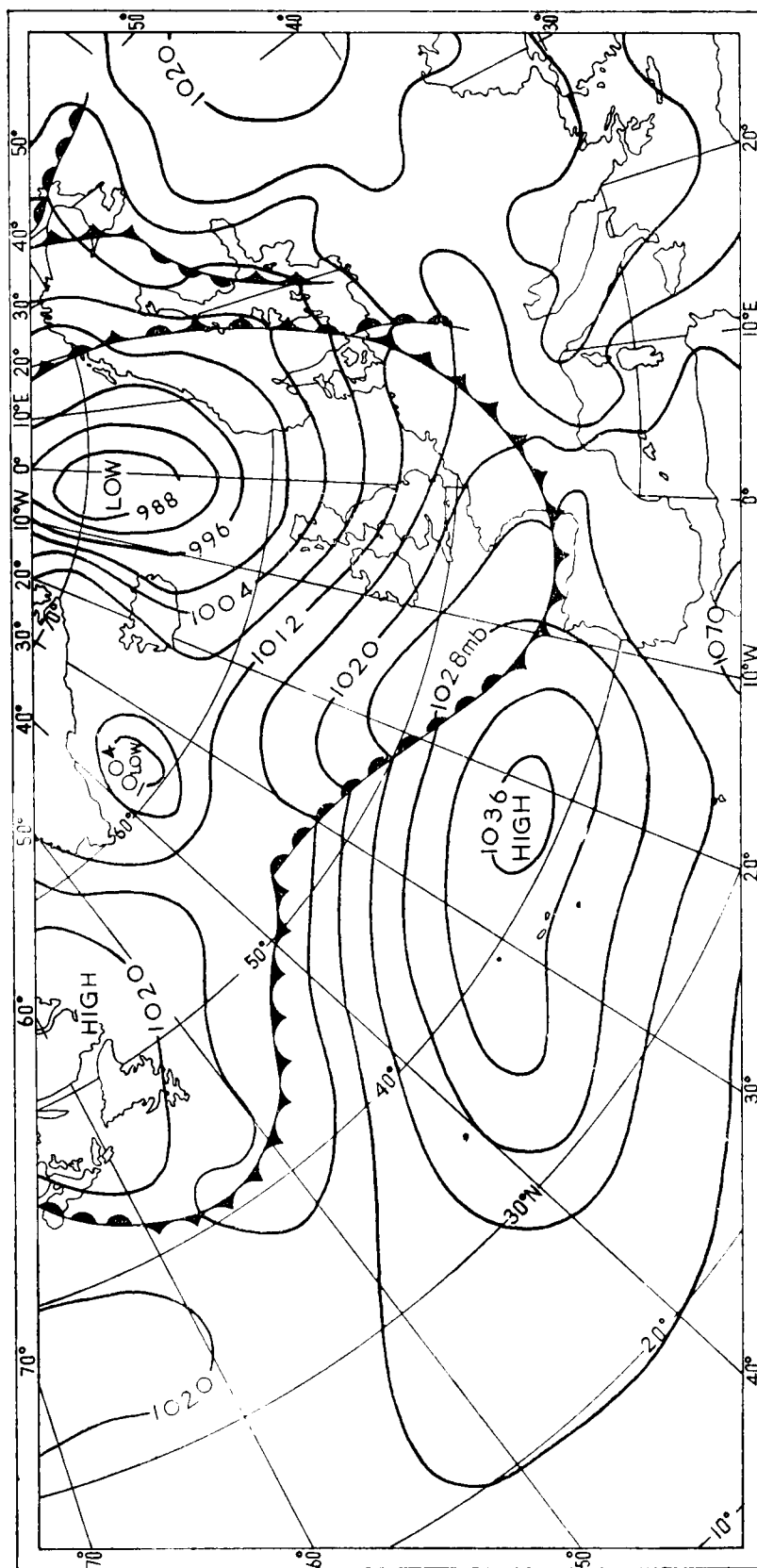


FIGURE 7—CRITERIA FOR A DRY SPELL SATISFIED
Surface chart for 1200 GMT on 9 June 1959.

TABLE II—THE NUMBER OF DRY SPELLS WHICH OCCURRED AND THE NUMBER FORECAST IN INDIVIDUAL YEARS

Synoptic type	I(NE)	II(E)	III(SE)	IV(S)	V(SW) <i>number of spells</i>	VI(W)	VII(NW)	VIII(N)	Total
1949	—	—	—	—	6(6)	3(2)	—	—	9(8)
1950	1(0)	1(0)	—	1(0)	5(3)	—	—	—	8(3)
1951	—	—	—	—	4(4)	3(0)	1(0)	1(1)	9(5)
1952	—	—	—	2(0)	6(5)	—	—	—	8(5)
1953	—	—	—	1(0)	3(3)	4(2)	—	1(0)	9(5)
1954	—	—	—	—	2(2)	1(0)	—	—	3(2)
1955	1(0)	—	—	2(0)	7(7)	1(1)	—	1(0)	12(8)
1956	1(0)	2(0)	—	1(0)	4(4)	3(0)	1(0)	—	12(4)
1957	—	—	—	1(0)	3(2)	—	—	1(0)	5(2)
1958	—	—	—	—	2(2)	—	1(0)	1(0)	4(2)
1959	2(0)	1(0)	—	2(0)	7(6)	1(0)	—	1(0)	14(6)
1960	—	—	1(0)	—	3(3)	1(0)	—	—	5(3)
1961	1(0)	—	1(0)	3(0)	3(3)	2(0)	1(0)	—	11(3)
1962	—	—	—	1(0)	4(3)	2(0)	—	—	7(3)
1963	1(0)	—	—	2(0)	3(3)	1(0)	—	—	7(3)
1964	—	—	1(0)	—	8(8)	5(0)	—	—	14(8)
Total	7(0)	4(0)	3(0)	16(0)	70(64)	27(5)	4(0)	6(1)	137(70)

Figures in brackets indicate the number of spells which would have been forecast.

The rules would have been of most use in 1949, 1952, 1954 and 1955 when over 60 per cent of spells of all types would have been forecast. They would have been of least use in 1956 and 1961 when only about 30 per cent would have been forecast.

A comparison of the results obtained by the original and revised models.—The comparison is based on the years 1951 to 1958 on which the original model was based. The original model² would have forecast 85 per cent of the Type V spells which actually occurred, also 8 spells of two days and on 8 occasions the forecast of a dry spell would have failed. The revised model would have forecast 94 per cent of the Type V spells, also 7 spells of two days and on one occasion the forecast of a dry spell would have failed.

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4. JACOBS, I.; 5-bzw. 40 jährige Monatsmittel der absoluten Topographien der 1000 mb-, 850 mb-, 500 mb- und 300 mb Flächen sowie der relativen Topographien 500/1000 mb und 300/500 mb über der Nordhemisphäre und ihre monatlichen Änderungen. *Met. Abh. Inst. Met. Geophys., Berlin*, **4**, Heft 1, Teil II, 1957, pp. 227–238.

LETTER TO THE EDITOR

Barometric pressures in central Iceland

An interesting article by Dr. I. Y. Ashwell, describing observations of atmospheric pressure on the central Iceland plateau and their reduction to sea level, was published in the February 1965 edition of the *Meteorological Magazine*.

Writing about a previous expedition to central Iceland, Dr. Ashwell says "It was not found possible to deduce sea-level pressures, because the readings were taken from aneroid barometers, and only differences between the readings at Station A and those at Reykjavik, on the coast, were considered."

The difficulties of correcting station-level pressures to sea level do not depend on the type of barometer used to make the measurements. It may be argued that aneroid barometers are too inaccurate to make it worth while converting their readings to sea level and this may well have been true of the instruments referred to by Dr. Ashwell. However, aneroid barometers with a performance as good as, or better than, the Kew pattern mercury barometer are now available: one such instrument was described by C. H. Hinkel in the *Meteorological Magazine* of June 1962.¹

Meteorological Office, Bracknell

W. R. SPARKS

Reply by Dr. I. Y. Ashwell:

The point of my remark, quoted by Mr. Sparks, is that the aneroid barometers which we had in 1956 and also in 1960, would not have justified the work of reduction to sea level. The Schools Exploring Society has always been very dependent on the loan of instruments from the Meteorological Office, and the only aneroids available at that time, to the best of my knowledge, were those of the Wheeler type. Any correction would have been difficult, if not impossible, and it was thought best to rely on the best available barometers for absolute readings, namely the long-range mercury type.

It will be of interest, however, that since 1962 the Icelandic Weather Office has been making weather observations in the summer near the site of the observations reported in my paper, and eventually hope to extend these throughout the year.² I am not certain whether pressure readings are made, as I am at present somewhat remote from North Atlantic weather charts, but I am sure that Mr. Sparks' letter may be of interest to the Icelandic Weather Office.

University of Alberta, Calgary, Canada.

I. Y. ASHWELL

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1. HINKEL, C. H.; A new precision aneroid barometer. *Met. Mag., London*, **91**, 1962. p. 154.
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REVIEWS

Krakatoa, by Rupert Furneaux. 9 in × 6 in, pp. 224, *illus.*, Prentice-Hall Inc., Englewood Cliffs, N.J., U.S.A., 1964. Price: \$4.95.

For the first time a comprehensive popular account has been written of the catastrophe that struck Java and Sumatra in 1883, a catastrophe which not only took the lives of an unknown number of people, but which was one of the greatest natural disasters of historic times. The official figure of 36,417 known deaths, attributed largely to the annihilating series of seismic sea waves which devastated the shores around the Sunda Straits, probably represents far less than the actual toll of life taken in the terrible hours between 1 p.m. on 26 August 1883 and noon on the following day.

Mr. Furneaux describes the stupendous power of this awful event in words both evocative and supremely imaginative, and he has attempted to explain the origin of the forces at work, which are by no means yet fully understood, in a way which is easy to understand and not seriously at variance with present-day scientific thinking. He has collected a great deal of information from a wide variety of sources, not all of them easily accessible today, and although he has

not presented this material in its most digestible form, it remains as a valuable compendium of the evidence which any patient reader should be able to sift.

Mr. Furneaux has presented all the available evidence and he has done so in the context of other well-documented catastrophes, so that Krakatoa's eruption is compared with that of nearby Tambora in 1815, Vesuvius in A.D. 79, Mt. Katmai in 1912, Mont Pelée in 1902, and others. It is a pity, however, that he has not mentioned the eruption at Ritter Island, in the Dampier Strait west of New Britain, some 3000 miles east of Krakatoa. This island, which was about 2600 feet in height, after some months of activity, disintegrated and collapsed on 13 March 1888, leaving a remnant only 350 feet high. The resulting sea wave swept neighbouring coasts to a height of 40 feet and thousands of people were drowned.

Geologists, naturalists, and perhaps meteorologists, may object to some of the things that Mr. Furneaux says: Krakatoa does not fall on or anywhere near the so-called 'Andesite Line', and surely butterflies cannot be "born in the ash"—they are much more likely to have migrated or been blown thither. More serious objections, however, concern the one rather inadequate map reproduced for the district. It has no scale, many of the places mentioned in the text are not shown and some place names, Tjaringin for example, are spelt incorrectly. Verbeek's diagram of the island is mentioned but is not reproduced. On the other hand, there are some excellent line drawings and photographs, including a good series of Anak Krakatoa in eruption.

This book will dispel many persistent misconceptions of Krakatoa's eruption, the most important of which is that there was little or no warning of the impending disaster. It is commonly thought, by those not familiar with the event, that the volcano, long dormant, disintegrated in a single colossal explosion when the build-up of gas pressure beneath it had exceeded a critical point. On the contrary, Krakatoa had been in violent eruption for more than three months before a single life was lost. Some idea of the magnitude of the forces involved can be gleaned from the fact that although an enormous amount of material had been ejected between 20 May, when the eruption began, and the climax on 26 August, internal pressure was able to build up between 23 and 26 August, when the vent was at least partially blocked, sufficiently quickly to cause the paroxysmal explosion which heralded collapse and engulfment of the island on the following day.

The book will be of great value to geographers and geologists as a reference work on Krakatoa and includes an excellent index and bibliography. It will be of great interest to meteorologists, since Mr. Furneaux has discussed in considerable detail several instances of large-scale weather effects which may have been caused by huge volcanic eruptions. He includes examples of prolonged and heavy rainfall, which, it has been suggested, occurred because of the presence of large quantities of volcanic ash at high altitudes, the phenomenon of the "year without a summer," and the magnificent sunrises and sunsets which many people will remember after the eruption on the island of Bali in 1963.

Finally, it will be good reading for anyone who wants to know what a volcano in action is like. The wealth of detail and repetition which this book contains may seem verbose and disordered in presentation but, to anyone who is involved in it, an eruption is a chaotic event, so that eye-witness accounts may well be somewhat incoherent.

J. H. LATTER

Convective motions in a free atmosphere, by N. I. Vul'fson (Translated from Russian). 9 $\frac{3}{4}$ in \times 6 $\frac{3}{4}$ in, pp. viii + 188, *illus.*, Israel Program for Scientific Translations; distributed by Oldbourne Press, 1-5 Portpool Lane, London, E.C.1., 1964. Price: 90s.

This is a translation of a Russian book published in 1961. It is not a textbook but gives the results of a series of investigations of convection carried out by the author between 1952 and 1956 using primarily a fast-responding aircraft thermometer. The outputs of this instrument, an accelerometer and a height and airspeed transducer, are fed to a multi-channel recorder. Humidity obtained from a dew-point recorder was available on only a small number of occasions and is discussed almost entirely in an appendix. The vertical velocity of the air was not measured, but the direction of its motion was inferred from the accelerometer or the change in the aircraft's height. Most of the results are based on the temperature record and a remarkably large amount of information about the nature of convection has been deduced from this instrument alone. Much of this information is factual but some of it depends on the manner in which the records are interpreted. Although there are many obvious errors, the translation is well done and only occasionally is the meaning obscure. The printing is clear and the graphs well reproduced but some of the photographs are lacking in detail.

The first chapter describes the instruments, gives some sample records and shows how they have been interpreted. The arbitrary division of some complex temperature 'pulses' into a series of independent simple pulses throws doubt on all the subsequent tables and graphs containing information about the horizontal dimensions of convective currents. The volume of air occupied by convective currents is unaffected by this division and is therefore more reliably established. The section on measurement in clouds is difficult to follow, but it is clear that large errors are expected due to evaporation even in a thermometer shielded from water drops. No attempt has been made to assess these errors.

In Chapter II a theoretical study is made of the problem of deducing the true dimensions and temperature excesses of convective currents from the records obtained from the aircraft which, of course, does not usually pass through the centres of the currents. Two sets of results are obtained, one on the assumption that the currents are in the form of jets, and the other that they are in the form of bubbles.

In Chapter III the main results are presented. These are in the form of graphs giving the distribution of size of convective currents and the distribution of their excess temperature. Some three-dimensional graphs (which are rather difficult to interpret) are also given to show the distribution of convective currents between different combinations of dimensions and excess temperature. All the graphs are given on the assumption that the currents are both jets and bubbles. Other information contained in tables includes the average dimensions of the currents, their number per square kilometre, the relative volume occupied by them, and the number of ascending currents warmer than the surrounding air. Most of this information is given at various heights and times of day, in different synoptic situations, and with different underlying surfaces. Finally in this chapter empirical relationships are given for the variation with height of some of the parameters and comparisons are made with theory.

In the final chapter convective motions in clouds are discussed. Only a few occasions were considered and the difficulty of temperature measurement in cloud makes the reliability of the results in this section very doubtful.

In the introduction it is stated that this book may be of interest to scientists in the field of atmospheric physics and in other fields. It is also stated that it may be useful to students at meteorological institutes and university physics faculties. It seems unlikely, however, that anybody other than specialists in the studies of convection will make much use of this book. To them, the wealth of novel information, although much of it is controversial, will certainly be worthy of close study.

D. R. GRANT

Problems in Palaeoclimatology, edited by A. E. M. Nairn. 10½ in × 7 in, pp. xiii + 705, *illus.*, John Wiley and Sons Ltd., Glen House, Stag Place, London, S.W.1, 1964. Price: 147s.

This book contains the proceedings of the palaeoclimates conference held at the University of Newcastle-upon-Tyne in 1963 under the auspices of NATO. The papers given at this conference have been grouped into chapters, each dealing with different types of evidence for past climates. At the beginning of each chapter there is a general summary of the theme of the chapter and of the papers it comprises, and at the end of each chapter there are the reports of discussions on the theme and a bibliography. The contents of the book are thus admirably laid out, with the many different aspects of palaeoclimate readily accessible. The chapters cover the geological, geophysical, biological and meteorological aspects of palaeoclimates. They concern the use of fossil plants as indicators of past climate, evidence of climate from coal, the recognition of ancient glaciations, Pre-Cambrian glaciation, geophysical techniques and ancient climates, theoretical considerations and Quaternary climates, Devonian and Permian climates, arid climates and wind direction studies, carbonates and evaporites, palaeontology and climate, and lastly, problems of sediments and soils.

One of the difficulties of palaeoclimatology is that it concerns several disciplines—palaeontology, ecology, geology, geophysics and meteorology among them, and no one person is likely to attain enough expertness in the whole field to present a clear and up-to-date account of the subject. However, in this book there is an effective substitute, a series of up-to-date papers by the leading authorities in the several fields, and written in such a way that they are understandable to the general reader. In fact the series of papers will prove most valuable in providing critical and readable accounts of past progress and future problems in paleoclimatology. For the specialist the bibliographies will also prove a useful addition to the literature of palaeoclimatology.

The introduction to the book, by W. H. Bucher, is really a concluding chapter which discusses trends of thought regarding interpretation of past climates. In particular, Bucher emphasizes the conflict between the geophysical evidence of shifting magnetic poles as evidence of changing latitudes and the geological and palaeontological evidence for changing climate. What is required is decisive geological and palaeontological evidence of former climates, against which the geophysical evidence can be weighed. The absence of such decisive evidence is revealed by many of the papers and the subsequent discussion of them, e.g. the difficulty of interpreting 'red beds' climatically and of the interpretation of fossil glacial deposits.

With the focus of the book on the whole of geological time, it is not surprising that not much attention is paid to detailed recent climatic change of the last million years or so and the possible meteorological causes of such changes. But in this field there are informative papers by P. A. Sheppard and H. H. Lamb which provide fundamental meteorological discussion to those interested in the course of the recent climatic changes.

The book is well illustrated with many figures and tables, and there are author, name and subject indexes. As an up-to-date textbook on palaeoclimates for students in the several fields involved, the book will be indispensable, and for the more general reader it will also be a useful introduction to the difficulties of the subject.

R. G. WEST

The flight of thunderbolts, by Sir Basil Schonland. 9 in \times 5 $\frac{3}{4}$ in, pp. 182, *illus.*, Clarendon Press, Oxford University Press, Amen House, Warwick Square, London, E.C.4, 1964. Price: 30s.

This is the second edition of a popular book by an acknowledged expert on lightning, which was first published in 1950. The present edition (at twice the original price) follows the same form as the previous book, but there has been some revision, particularly in bringing the reader up to date with the latest theories of charge generation and separation within a thunderstorm cloud. The author wisely cautions the reader against accepting any one theory as representing the last word on the subject.

The book is simply and interestingly written, mingling historical facts with authoritative advice. It is strongest in its discussion of the lightning flash and its effects, towards the knowledge of which the author's own researches in South Africa contributed so much. From the meteorologist's point of view it is a pity that the book should be weakest in chapter 7 when discussing thunderstorm structure and cloud physics. There are two statements on p. 142 which should not go unchallenged, one that ice pellets of only 0.001 cm in diameter are big enough to sweep up smaller unfrozen droplets (0.01 cm is nearer the mark) and the other that a hailstone could be kept within a cloud by an updraught exceeding twenty-five miles per second! These are no doubt misprints, but there are other weaknesses and it is better to follow the author's own advice—"for a fuller account of the present position on the complex subject of water and ice in thunderclouds the reader is recommended to Professor B. J. Mason's monograph." (In that monograph one reads "for a more detailed account of these pioneer experiments and of the fascinating history of the lightning conductor the reader is recommended to read "The Flight of Thunderbolts" by B. F. J. Schonland", so honours are about even).

For the reader interested in the history of science and for the practical man interested in the protection of structures against lightning there is much to recommend in this book.

R. F. JONES

To face p. 257.



Photograph by W. Bird

PLATE I—SIR GRAHAM SUTTON, C.B.E., F.R.S.

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RETIREMENT OF SIR GRAHAM SUTTON, C.B.E., F.R.S.

In September 1953 we welcomed Dr. O. G. Sutton, as he then was, as Director of the Meteorological Office in succession to Sir Nelson Johnson. Now, twelve years and one month later, we bid him farewell on his retirement from the Office to take over wider responsibilities.

In 1953 he was best known to most of us for his research on the turbulent structure of the lower atmosphere, and as a scientist with an international reputation—a reputation gained as a result of work as a member of the Office staff. He was however also an experienced administrator in the scientific field. This was fortunate for the Meteorological Office, which was then on the threshold of a decade of great change. Prior to the Second World War there had been very little officially organized research within the Office. In a reorganization after the war Sir Nelson Johnson laid the foundations for a planned research side of the Office. The tempo of such changes is inevitably slow and to Sir Graham (he was knighted in 1955) fell the task of building on the foundations laid by his predecessor. On 30 September 1965 he leaves an organization with a strong and closely integrated structure combining services, research and administration. In this technological age it is widely held that the research worker should be in close contact with the practitioner who uses the results of research. In the Meteorological Office, with its facilities for interchange of men and ideas between the Services and Research Directorates, the contact could not be closer. It was Sir Graham also who brought about a long-standing hope of many of the staff for a unified headquarters to replace the old tripartite split between London, Harrow and Dunstable.

However, organization and staff are not sufficient without the material facilities and Sir Graham has ensured that the equipment made possible by technical advances has become available to the Meteorological Office. The electronic computer is certainly not the only example of such equipment but there is something particularly appropriate in the circumstance that the Director-General who was responsible for getting our first computer—primarily for research purposes—should also be with us long enough to see the installation of its successor, which is intended to carry out a large, routine task. However, it has not been only the research work of the Office which has concerned Sir Graham. The past decade has seen a big increase in the importance of the meteorological services for those parts of the community not concerned with aviation. A pattern has been laid which will allow expansion if this seems desirable in the interests of the community.

Sir Graham has been unstinting in his efforts in the international fields connected with the development of the science and practice of meteorology. For the twelve years from 1953 to 1965 he was a member of the Executive Committee of the World Meteorological Organization.

Since his appointment as head of the Meteorological Office a number of marks of recognition of his status as a scientist have been conferred on him, including Presidency of the Royal Meteorological Society from 1953 to 1955, the Symons Gold Medal in 1959, and the Presidential Gold Medal of the Society of Engineers in 1957. But his position as President of the Institution of Professional Civil Servants from 1957 to 1961 was indicative of a characteristic which naturally received less publicity than his scientific work, namely a great concern for the conditions of work for his staff.

During his last year as Director-General his wide experience has been called upon to assist in the task of forming the Natural Environment Research Council and during the past few months he has been chairman of that body as well as Director-General of the Meteorological Office. He leaves us to devote his time to this new organization. All who have served under him will wish him good luck in this wider field and feel glad that a meteorologist has been chosen for this important work.

A. C. BEST

RETIREMENT OF DR. R. C. SUTCLIFFE, C.B., O.B.E., F.R.S.

On 31 August Dr. R. C. Sutcliffe retired from the post of Director of Research of the Meteorological Office, thus completing 38 years work in the Office.

Although Dr. Sutcliffe was born in Wales in 1904 the family soon returned to their native Yorkshire and his early education was at the Whitcliffe Mount Grammar School, Cleckheaton. He went from there to the University of Leeds to read mathematics, and afterwards to the University College of North Wales, Bangor, where he gained his doctorate. In his Meteorological Office appointments he saw service at home and overseas (Malta) and during the war served first as a Squadron Leader, RAFVR in France from 1939 to 1940, then as Senior Meteorological Officer of the No. 3 Bomber Group of the RAF (1941-44) and finally as Chief Meteorological Officer for the RAF in Germany from 1944-46 with the rank of Group Captain. He has thus had an exceptionally wide range of experience and carried great responsibilities in his work as an operational meteorologist. No one knows better the difficulties (and delights) of forecasting, and his well-known *Meteorology for aviators* (1938) is evidence of his skill in this field.

It is, however, as a theoretical meteorologist that his name will live long in the history of meteorology. In the development of our science there are a handful of contributions—perhaps a dozen or so—that stand out as landmarks. Among these must be placed Dr. Sutcliffe's papers on development theory. They provide in part the basis for the powerful dynamical methods that have now led to the realization of mathematical forecasting, and the science of the atmosphere is forever indebted to the physical insight and mathematical skill that enabled him to utilize to such great advantage the experience gained in long hours at the forecasting bench.

His work has been recognized, not only in Britain, but elsewhere. He was elected to the Royal Society in 1957 and received from the Royal Meteorological

Society the Buchan Prize in 1950 and its highest award, the Symons Gold Medal, in 1955. In 1959 the Physical Society awarded him the Charles Chree Medal and in 1963 his career culminated in the award of the International Meteorological Organization Prize by the World Meteorological Organization. He has also acted as President of the Commission for Aerology of WMO (1957-61) and is now Chairman of its Advisory Committee.

Dr. Sutcliffe became the first Director of Research of the Meteorological Office in 1957. The concept of a fully-developed research side, which had been growing steadily since the formation of the Meteorological Research Committee in 1941, was not completely realized until 1956 when the Brabazon Committee recommended the creation of separate Directorates of Research and Services within the Office. To Dr. Sutcliffe fell the onerous task of building up what virtually amounted to an institute of meteorology within the framework of a governmental establishment. The success which has attended his efforts is now visible to all, but it is only those inside the Office who can realize how much we owe to his wisdom, drive and enthusiasm.

Reggie Sutcliffe, as he is invariably known to us, has always been immensely popular with his colleagues. To me, as Director-General, he has been not only a close friend but the wisest and most cheerful of counsellors. We wish him and his wife many serene years of well-earned retirement from the service to which he has added such lustre.

O. G. SUTTON

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A TEST OF KENNINGTON'S METHOD OF FORECASTING THE TIME OF CLEARANCE OF RADIATION FOG

By D. J. HEFFER

Basis of the investigation.—Kennington has described a method of forecasting the time of clearance of radiation fog.¹ To forecast the time of clearance it is necessary to forecast the clearance temperature and Kennington says that "one way of doing this is to take the surface temperature required to give a saturated adiabatic lapse rate to the top of the inversion". He then derives the time of clearance from an estimate of the amount of solar radiation required to raise the temperature from its dawn value to the clearance temperature.

He admits that at the time of writing he had been unable to test the method exhaustively and quotes preliminary tests on five particular occasions at Kew. The object of this paper is to report on a more comprehensive test based on the Cardington Balthum ascents. Special reports of wind and temperature are made at Cardington daily at about 0000, 0600, 1200 and 1800 GMT (and on occasions at intermediate hours) except on public holidays and on occasions of strong or gusty winds, or when thunderstorms are in the vicinity. Instruments are carried aloft by means of a tethered kite-balloon and readings are made at the surface, 9, 15, 21, 30, 45, 75 and 150 metres then every 75 metres up to 600 or 1200 metres, together with any special inversion points. Heights are usually converted to pressure in millibars for convenience of plotting on the standard tephigram.

The paper is in two parts. In the first the clearance time is derived directly from the 'dawn' ascents; this part of the paper shows the degree of accuracy which is likely to be attained by a forecaster who is fortunate enough to have a dawn ascent available. Most forecasters in the British Isles are, however, dependent on data from a midnight upper air ascent and the second part of the paper suggests how a midnight Balthum ascent may be modified to give an estimate of the fog top at dawn.

Test based on dawn ascents.—For the purpose of the test a period of the night with visibility less than 1100 yards with an average of $\leq 2/8$ low/medium cloud from onset to dispersal constitutes a radiation fog. All dates when there was radiation fog at any one of six stations in eastern England during the four years 1960–63 were listed and data were extracted for those on which a Balthum ascent was made at Cardington at 0600 GMT. This gave a total from the six stations of 401 reports of a period of radiation fog on 110 different dates. On occasions when clearance occurred before 0600 GMT it was possible to use an 0300 GMT ascent to find the forecast clearance time.

On all the Balthum ascents there was a clearly defined nose on the dew-point curve and this was taken to mark the fog top. (This does not mean necessarily that there was fog at Cardington as the formation of fog also depends on surface conditions.) In all cases the fog-top estimate was below the top of the inversion, and in many cases it was well below. It was therefore decided to take as the clearance temperature the surface temperature required to give a saturated adiabatic lapse rate to the top of the fog (not the top of the inversion as recommended by Kennington). This is in accord with the practice recommended by Barthram,² whose diagrams were used as the most convenient way of computing clearance times.

The six stations used in the original tests were Bedford, Bassingbourn, Wyton, Honington, Mildenhall and Watton. Details are given in Table I together with details of two other stations, Wittering and Cottesmore, which are mentioned later.

TABLE I—DETAILS OF STATIONS USED IN THE INVESTIGATION

Station	Height above mean sea level	Approximate distance from Cardington	Approximate bearing from Cardington	Number of reports
	<i>feet</i>	<i>nautical miles</i>	<i>degrees</i>	
Bedford	293	10	280	51
Bassingbourn	81	6	100	87
Wyton	135	17	010	97
Honington	175	35	070	51
Mildenhall	30	30	050	64
Watton	200	50	050	51
Wittering	275	32	350	} Pilot scheme only
Cottesmore	460	39	350	

The results are shown in Figure 1 which includes all reports except 22 which gave forecast clearance temperatures below 0°C. (The cases with forecast clearance temperatures below 0°C had irregular clearance times. The forecasts were invariably too early and in a third of the cases the fog failed to clear that day. They were insufficient in number for detailed study with a view to finding a delay factor.) Forecast clearance times can be readily estimated to the nearest quarter of an hour; actual clearance times (*H*) observed at the stations are

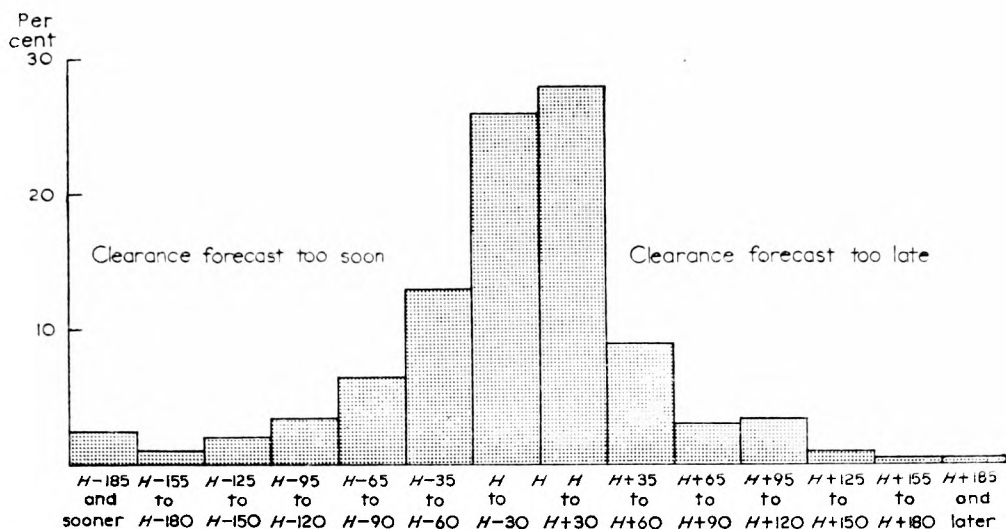


FIGURE 1—HISTOGRAM SHOWING PERCENTAGE DISTRIBUTION OF ERRORS IN FORECAST TIMES OF FOG CLEARANCE

When the forecast time of clearance corresponds with the actual time of clearance (H) the occasions are apportioned between the periods H to $H + 30$ minutes and H to $H - 30$.

normally correct to well within a quarter of an hour during daylight hours. Differences between forecast and actual clearance times are given to the nearest five minutes. Kennington's method gave the time of clearance to within $\frac{1}{2}$ an hour on 54 per cent of occasions and to within 1 hour on 76 per cent of occasions. It made no great difference to these percentages whether two years were considered instead of four or whether the stations were considered individually or in a group. The test confirms Kennington's method as a most useful means of forecasting times of fog clearance when a reliable measurement of the height of the fog top is available. It also shows that the measurement can be used over a wide area of eastern England with fogs varying in thickness between 5 and 40 mb, and at stations with heights above mean sea level varying over quite a wide range. No adjustment to the height above sea level of the fog top as measured at Cardington is necessary.

The percentage of other instances when there were big forecast errors was not large but, as a big error could cause serious inconvenience to the user of the forecast, cases of large forecast errors have been examined individually. The first thing to note is that large errors generally apply to a particular place and not to the area as a whole. The biggest error (apart from those arising from temperatures below freezing) was a discrepancy of $4\frac{1}{4}$ hours at Bassingbourn on 26 November 1962, but at the neighbouring stations of Bedford and Wyton the forecast was correct to within $\frac{3}{4}$ hour. It is not possible to go into details of every discrepancy here but Kennington's method applies strictly to radiation fogs which form and disperse *in situ*, and in a number of cases the discrepancies could be attributed to a light drift from the fens; this was quite marked at Wyton and also to a lesser extent at Watton and Mildenhall. In a light north-easterly wind, fog at Bassingbourn tends to clear later than a general forecast for the area would suggest and the case of 26 November 1962 was an extreme example. Local peculiarities are well known to forecasters with long experience of particular stations and the influence of the fens on fog clearance has been discussed by Freeman.³

The contrast between Bedford and Wittering is interesting. Both stations are at roughly the same height above sea level. Bedford is on the flat top of a hill where radiation fog rests where it forms and 71 per cent of the forecasts were correct to within an hour; but Wittering is on the side of a hill where fog is liable to drift and only 45 per cent of forecasts in the pilot scheme were correct to within an hour. Only 50 per cent were correct to within an hour for Cottesmore, another station liable to topographical effects. Wittering and Cottesmore were omitted from the main test and used in a separate investigation.

In Table II, data for the six stations are analysed for each month to show for each hour the frequency of fog clearance expressed as a percentage of the total number of occasions of fog in each month. Thus, in June, a forecast clearance time of 0700 GMT would be correct to within $\frac{1}{2}$ hour on 43 per cent of occasions.

TABLE II—DISTRIBUTION OF CLEARANCE TIMES OF RADIATION FOG

Time (GMT)	0430 to 0530	0530 to 0630	0630 to 0730	0730 to 0830	0830 to 0930	0930 to 1030	1030 to 1130	1130 to 1230	1230 to 1330	Did not clear	Number of reports
<i>percentage of total for each month</i>											
January	3	3	3	3	6	16	37	10	3	16	31
February		3	10	22	16	10	26	13			31
March		6	24	19	17	17	11	3	3		46
April	4	35	19	15	23	4					26
May	43	16	16	9	16						12
June	14	29	43	14							14
July	17	41	17	8	17						12
August	34	21	18	27							33
September	4	12	24	18	21	17	4				66
October		8	11	12	31	19	10	8	1		75
November		6	6	26	29	20	13				28
December		4	4	8	8	11	14	8		43	27

Examination of midnight ascents.—The foregoing describes tests based on dawn ascents. It now remains to show how a midnight ascent may be used to give an estimate of the fog top at dawn.

Occasions when both a midnight and a 0600 GMT Balthum were available were examined in conjunction with synoptic charts and it was evident that in many cases which at first sight had been accepted as radiation fogs the difference between midnight and 0600 GMT profiles were due, at least in part, to advection. For this part of the investigation it was necessary to use data free, as far as possible, from advection effects and it was therefore decided to use only data for which the forecasts produced by the test method had been accurate to within an hour and for which scrutiny of synoptic charts gave no grounds for suspecting advection effects between midnight and 0600 GMT (such as the passage of minor fronts or a change of moisture content in the lower layers of the atmosphere associated with a shift of wind bringing moister air off the sea). In the four years 1958, 1959, 1961 and 1962, 122 examples of fog were examined for Wyton (the station chosen for this part of the investigation) and only 40 satisfied these conditions. These statistics are in themselves some measure of the frequency of occurrence of radiation fogs without advection effects.

Comparison of the midnight and 0600 GMT Balthums showed that the height of the top of the radiation inversion on the temperature curve was generally about 35 mb above the ground, though there were occasional wide variations from this value. Once formed, the nose on the dry-bulb temperature curve rarely

rose by more than 5 mb in the six-hour period. The average rise was 2–3 mb and the average decrease in temperature at the nose was 1.5°C . This information forms the basis of the following rule for estimating the fog top at dawn from the midnight ascent:

- (i) If the nose has already formed on the temperature curve, the level is raised by 5 mb and the temperature is decreased by 1.5°C and this point is joined to the night minimum temperature by a straight line on the tephigram. It is assumed that the dew-point curve changes little in the period from midnight to dawn. The point where the straight line and the dew-point curve intersect (point O in Figure 2) represents the fog top at dawn for use in Kennington's method.
- (ii) If a nose has not yet formed on the temperature curve at midnight, the point 35 mb above the ground is joined to the night minimum surface temperature (i.e. without subtracting 1.5°C from the temperature) and the fog top estimated as before (point O in Figure 3).

To test this rule the assumption was made that it is possible to forecast accurately the night minimum temperature, and the observed night minimum temperatures at Wyton were used in the test. The figures given above show that radiation fogs with no advection occur on only about 33 per cent of foggy nights, which limits the application of the rule, but on those 40 occasions at Wyton which were used to test the rule, 23 forecasts (57 per cent) of the time of fog clearance were correct to within $\frac{1}{2}$ hour and 35 forecasts (87 per cent) were correct to within one hour.

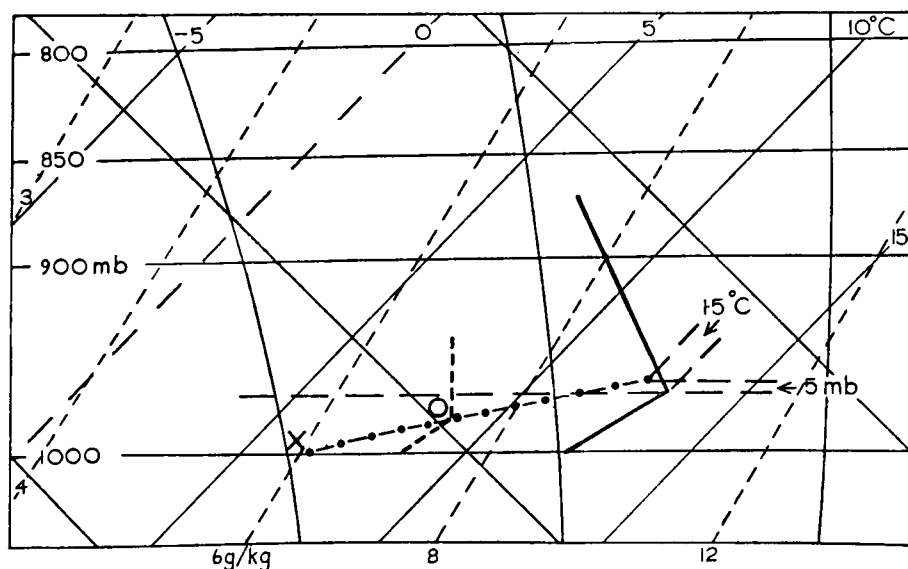


FIGURE 2—CONSTRUCTION FOR FOG-TOP ESTIMATE FROM A MIDNIGHT BALTHUM WHEN THE INVERSION NOSE HAS ALREADY FORMED

— Dry-bulb curve - - - Dew-point curve
 Construction for fog-top estimate. ● Estimated fog top
 X Night minimum temperature

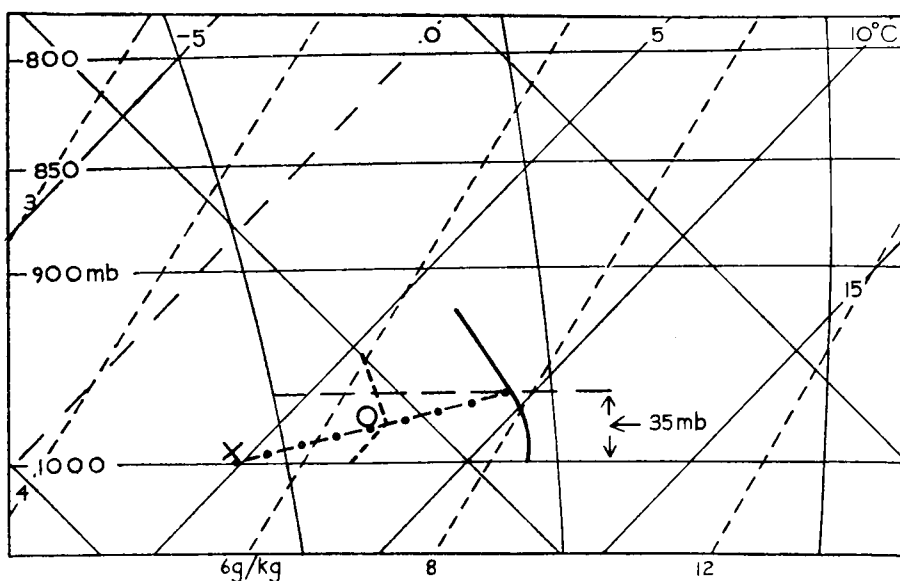


FIGURE 3—CONSTRUCTION FOR FOG-TOP ESTIMATE FROM A MIDNIGHT BALTHUM WHEN THE INVERSION NOSE HAS NOT YET FORMED

— Dry-bulb curve - - - Dew-point curve
 Construction for fog-top estimate ● Estimated fog top
 X Night minimum temperature

When the dew-point curve was isothermal or still increasing with height at the point of intersection, the position of the fog top was not so clearly defined. The clearance times of the deeper fogs tended to be underestimated.

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THE FORECASTING OF SHOWER ACTIVITY IN AIRSTREAMS FROM THE NORTH-WEST QUARTER OVER SOUTH-EAST ENGLAND IN SUMMERTIME

By C. A. S. LOWNDES

Introduction.—The purpose of this investigation was to distinguish between synoptic situations when polar airstreams brought widespread showers to south-east England between 0900 and 2100 GMT and similar situations when the shower activity was slight. The investigation was restricted to airstreams which approached the British Isles from the north-west quarter. This restriction was achieved by including only those days when the surface isobars over England at midday showed a flow from between west and north-west inclusive and the polar front lay to the south of the British Isles or had cleared south-east England by 0600 GMT. Occasions were not included if a front was situated over south-east England between 0900 and 2100 GMT or if the precipitation was not

mainly showery. The classification of the intensity of shower activity was based on reports from eight stations in south-east England in the months May to September during the 13-year period from 1952 to 1964. From 1962, the stations were Kew, London (Heathrow) Airport, Thorney Island, Hurn, Wattisham, Gorleston, Mildenhall and Cardington. For other years, one or two of these stations were not available and adjacent stations were substituted. From the Beaufort letters in the *Daily Weather Report* the total number of mentions of slight, moderate and heavy showers at the eight stations during the period 0900 to 2100 GMT was obtained for each day. From these figures, the intensity of shower activity was classified as follows:

A Widespread showers with a good proportion of moderate or heavy showers (8 or more mentions of showers; more than 25 per cent moderate or heavy showers).

B Widespread showers with few moderate or heavy showers (8 or more mentions of showers; 25 per cent or less of moderate or heavy showers).

C Few showers (less than 8 mentions of showers).

D No showers.

A note was made of thunder or hail reported between 0900 and 2100 GMT at any station in south-east England included in the *Daily Weather Report*. Surface reports were supplemented by sferic (atmospherics) observations during the same hours of the day.

The factors which were considered.—It is reasonable to associate the degree of shower activity primarily with the degree of instability of the lower troposphere as indicated by dry-bulb temperatures. Instability can be assessed in a simple fashion in various ways, of which seven were chosen for this investigation,* (1) the 1000–500 mb thickness anomaly, (2) the 1000–700 mb thickness anomaly, (3) the 700 mb temperature anomaly, (4) the Boyden instability index,¹ (5) the Rackliff instability index,² (6) the Jefferson instability index³ and (7) the modified Jefferson instability index.⁴

The thickness anomalies are departures from a climatological normal of thickness values and are closely related to the general excess or deficiency of air temperature which in turn is related to the degree of instability resulting from surface heating. The anomaly of 700 mb temperature is a fair measure of the instability attainable between the ground and the freezing-level. The instability indices, which were all devised for thunderstorm forecasting, are measures of instability which dispense with climatic normals. Apart from the humidity measurements inherent in the Rackliff and Jefferson indices, humidities in the troposphere were not considered because the variations in space and with time are large and difficult to forecast and because a high relative humidity may be simply the consequence of the evaporation of raindrops from a shower and may not be representative of the airmass. However, it became clear that the level of surface pressure was a useful predictor in association with the temperature and thickness anomalies, probably because of the well-known association between high surface pressure and relatively dry air aloft.

*For the years 1952 to 1955, solar radiation and lag corrections have been applied to the upper air temperatures and thicknesses to make them comparable with the data for 1956 to 1964 to which the corrections had already been applied.

Other factors considered included the position of the associated depression, surface troughs which moved across England, uniform cyclonic isobars over England and the effect of fast-moving warm fronts from the west.

Association with surface synoptic features.—

The position of the associated depression at midday.—Table I shows for each class of shower activity the number of occasions when the depression with which the polar air was associated was situated in a particular locality.

TABLE I—SHOWER ACTIVITY RELATED TO POSITION OF ASSOCIATED DEPRESSION AT MIDDAY (MAY–SEPTEMBER 1952–64)

Position of depression	Class of shower activity			
	A	B number of occasions	C	D
Arctic	0	0	1	3
Iceland	0	1	1	0
Norwegian Sea	5	1	14	10
Scandinavia	16	10	11	14
North of Scotland	6	5	6	5
Scotland	10	0	0	0
North Sea	17	5	6	2
Denmark	2	0	3	0
Germany	0	0	0	1
All areas	56	22	42	35

On all 10 occasions when the depression was situated over Scotland there were widespread showers over south-east England with a good proportion of moderate or heavy showers (class A). On 73 per cent of occasions when the depression was over the North Sea there were widespread showers (classes A and B). On 80 per cent of occasions when the depression was situated over the Norwegian Sea there were few showers or no showers (classes C and D). In general, the nearer the depression was to the British Isles, the more intense was the shower activity in south-east England. This suggests that the isobaric curvature and the level of surface pressure over the British Isles might be useful predictors.

The curvature of the surface isobars over England.—On many days of widespread showers, a surface trough moved eastwards or southwards across England. Of the troughs which moved eastwards, 70 per cent were major features with the trough axis some 600 to 1000 miles in length and 30 per cent were minor perturbations with the trough axis some 200 to 600 miles in length. Of the troughs which moved southwards, 30 per cent were major features and 70 per cent were minor perturbations. On other days of widespread showers there were uniform cyclonic surface isobars over England. Table II shows the number of these occasions for each class of shower activity.

TABLE II—SHOWER ACTIVITY RELATED TO THE CURVATURE OF THE SURFACE ISOBARS OVER ENGLAND (MAY–SEPTEMBER 1952–64)

	Class of shower activity			
	A	B number of occasions	C	D
Surface trough moved eastwards across England	25	7	4	2
Surface trough moved southwards across England	9	4	3	0
Uniform cyclonic isobars over England	9	3	3	1
Neither surface trough nor uniform cyclonic isobars	13	8	32	32
Total	56	22	42	35

On 58 per cent of occasions of widespread showers (classes *A* and *B*) a surface trough moved eastwards or southwards across England. Of the 27 days on which a major surface trough moved across England, all but one were associated with widespread showers and 21 (78 per cent) with thunder. Of the 27 days on which a minor perturbation moved across England, 19 (70 per cent) were associated with widespread showers and 10 (37 per cent) with thunder. Of the 16 days with uniform cyclonic isobars over England, 12 (75 per cent) were associated with widespread showers and 9 (56 per cent) with thunder. There were no occasions of widespread showers when the isobars over England were anticyclonic. On 83 per cent of occasions of few showers or no showers (classes *C* and *D*) there were neither surface troughs nor uniform cyclonic isobars. On 26 per cent of occasions of few showers or no showers, the isobars over England were anticyclonic.

Association with 700 mb temperature and surface pressure.—The following data were extracted for the period 1952–64:

- (i) The 700 mb temperature anomaly at Crawley for 1200 GMT (1500 GMT before 1957); for 1952, Larkhill was used. The anomaly was based on the 5-day mean temperatures given in Table III.
- (ii) The mean sea level pressure at Heathrow for 1200 GMT.

TABLE III—FIVE-DAY MEAN 700 MB TEMPERATURE AT CRAWLEY* IN °C

Period	Mean	Period	Mean	Period	Mean
1–5 May	–6	30 June – 4 July	–1	29 Aug. – 2 Sept.	–1
6–10	–6	5–9 July	0	3–7 Sept.	–1
11–15	–5	10–14	0	8–12	–1
16–20	–5	15–19	0	13–17	–1
21–25	–4	20–24	0	18–22	–2
26–30	–4	25–29	0	23–27	–2
31 May – 4 June	–3	30 July – 3 Aug.	0	28 Sept. – 2 Oct.	–2
5–9 June	–3	4–8 Aug.	0		
10–14	–3	9–13	0		
15–19	–2	14–18	0		
20–24	–2	19–23	0		
25–29	–1	24–28	0		

*Obtained from 5-year monthly means⁵ for the period 1951–55 (Larkhill 1951–52, Crawley 1953–55).

Rain showers.—A diagram was plotted (Figure 1) of the 700 mb temperature anomaly at Crawley against the mean sea level pressure at Heathrow. The various intensities of shower activity are indicated by symbols, class *A* by a black triangle, class *B* by an open triangle, class *C* by a dot and class *D* by a cross. The diagram can be divided into two areas as indicated. Of the occasions within area I, 87 per cent were associated with widespread showers (classes *A* and *B*) representing 91 per cent of all occasions of widespread showers. Of the occasions within area II, 90 per cent were associated with few showers or no showers (classes *C* and *D*) representing 86 per cent of all occasions of few showers or no showers. Assuming that the two predictors could be forecast and the diagram was used to forecast either widespread showers or few showers/no showers, a 'skill score' of 0.77 would be obtained. The skill score, S ,⁶ is defined by

$$S = \frac{\text{number of correct forecasts} - \text{number correct by chance}}{\text{total number of forecasts} - \text{number correct by chance}}$$

It ranges from 0 for no success to 1 for complete accuracy.

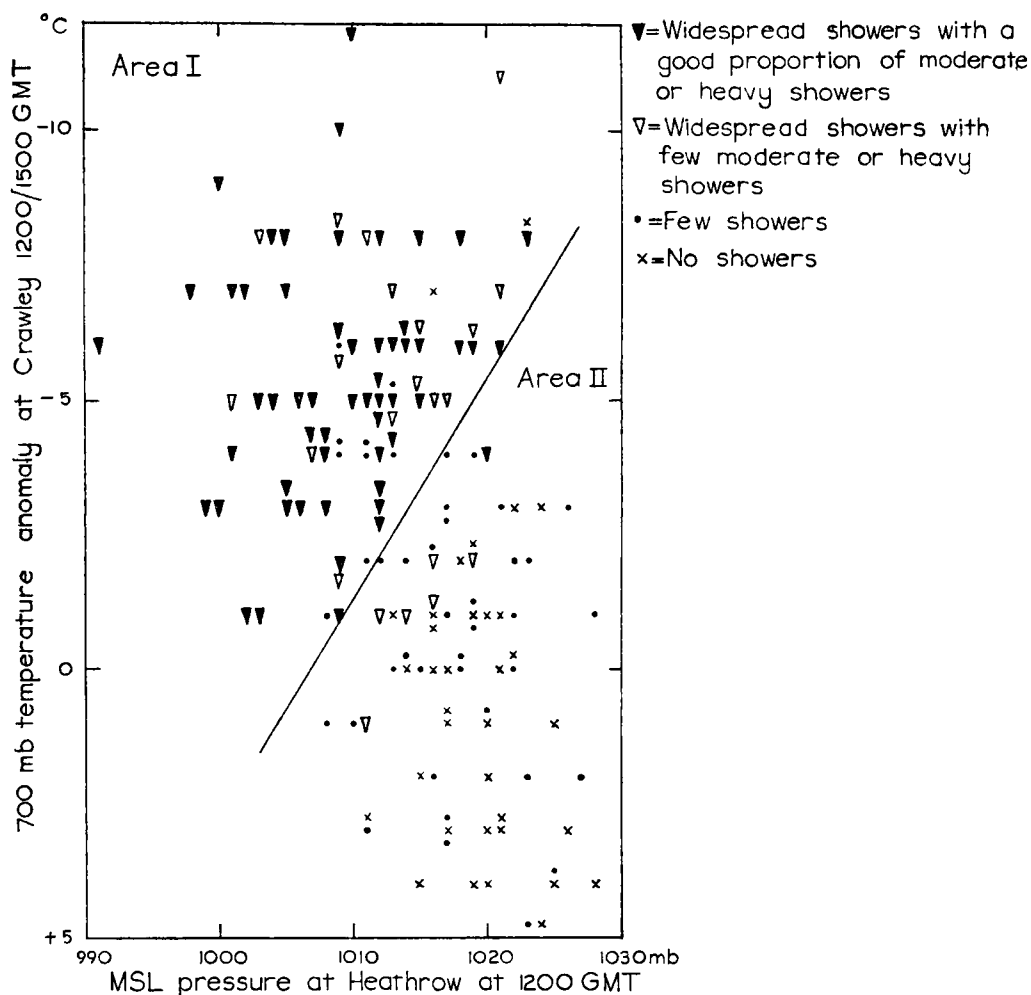


FIGURE 1—SHOWER ACTIVITY IN SOUTH-EAST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

The line divides the diagram into area I containing most of the occasions of widespread showers and area II containing most of the occasions of few or no showers.

Rainfall amount.—A similar diagram (Figure 2) was plotted with symbols representing the average rainfall between 0900 and 2100 GMT for the eight stations in south-east England for each day examined. The diagram can be divided into the same two areas which were used in Figure 1. Of all occasions within area I, 90 per cent were associated with an average rainfall at the eight stations of 0.1 millimetres or more, representing 89 per cent of all occasions of 0.1 mm or more. Of the occasions within area II, 88 per cent were associated with less than 0.1 mm, representing 89 per cent of all occasions of less than 0.1 mm. If the diagram were used to indicate an average rainfall of either 0.1 mm or more or less than 0.1 mm, a skill score of 0.78 would be obtained.

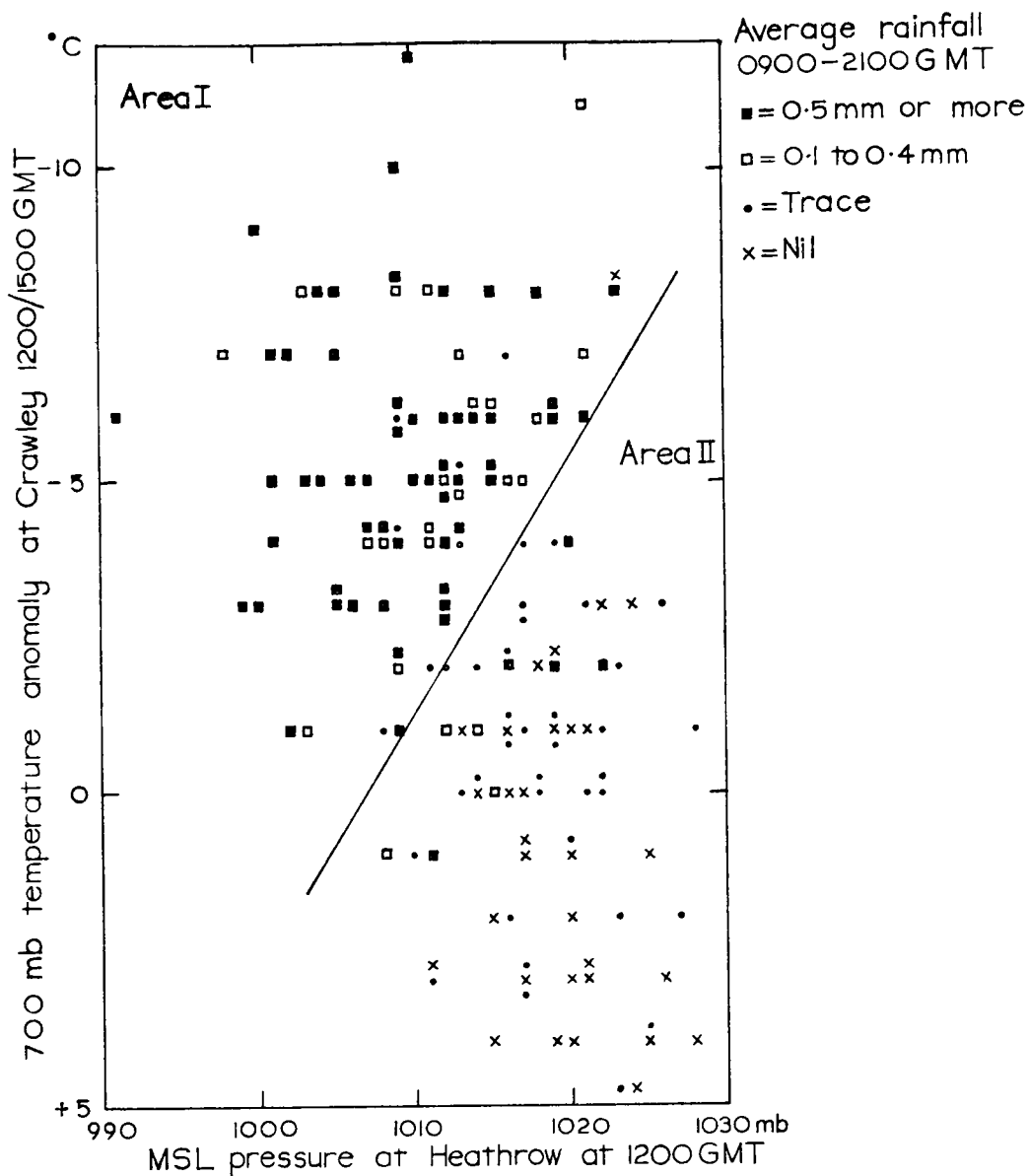


FIGURE 2—AVERAGE RAINFALL FOR EIGHT STATIONS IN SOUTH-EAST ENGLAND FOR EACH INDIVIDUAL DAY ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

Areas I and II are the same areas as in Figure 1.

Of all occasions within area I, 66 per cent were associated with an average rainfall of 0.5 mm or more, representing 92 per cent of all occasions of 0.5 mm or more. Of the occasions within area II, 93 per cent were associated with less than 0.5 mm, representing 71 per cent of all occasions of less than 0.5 mm. If the diagram were used to indicate an average rainfall of either 0.5 mm or more or less than 0.5 mm, a skill score of 0.58 would be obtained.

Figure 3 shows the highest and lowest rainfall amounts plotted against the average amount for the eight stations in south-east England for each day examined. For an average value of up to 1 mm, the highest value is likely to be about four times the average and for average values of 2 mm or more, about three times the average. For an average value of up to 1.7 mm, the lowest value was nil or a trace and for an average value above 1.7 mm the lowest value varied between nil and 1 mm. It is clear that however widespread the showers, some places are likely to escape with little or no rain.

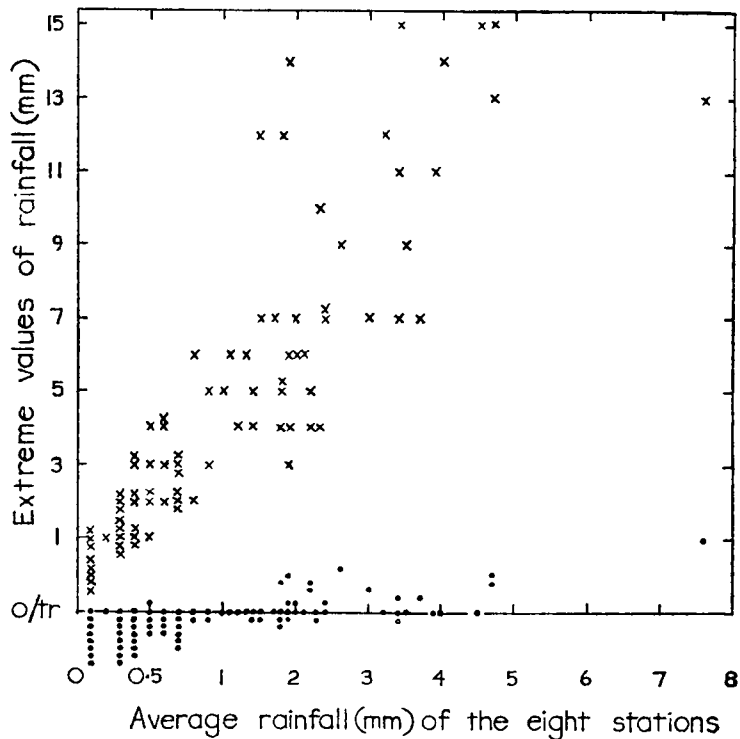


FIGURE 3—THE HIGHEST AND LOWEST RAINFALL AMOUNTS (0900–2100 GMT) ASSOCIATED WITH AVERAGE VALUES FOR EIGHT STATIONS IN SOUTH-EAST ENGLAND

x Highest individual values • Lowest individual values

For some values of the average rainfall the lowest amount was zero on several occasions and such occasions are plotted below the axis.

Thunder and hail.—A diagram was plotted (Figure 4) of the 700 mb temperature anomaly against mean sea level pressure with symbols representing thunder or hail. If no thunder or hail was reported, a cross was plotted. The diagram can again be divided into the same two areas. Of all occasions within area I, 72 per cent were associated with thunder, representing 89 per cent of all occasions of thunder and 35 per cent with hail, representing 97 per cent of all occasions of hail. Of the occasions within area II, 90 per cent were associated

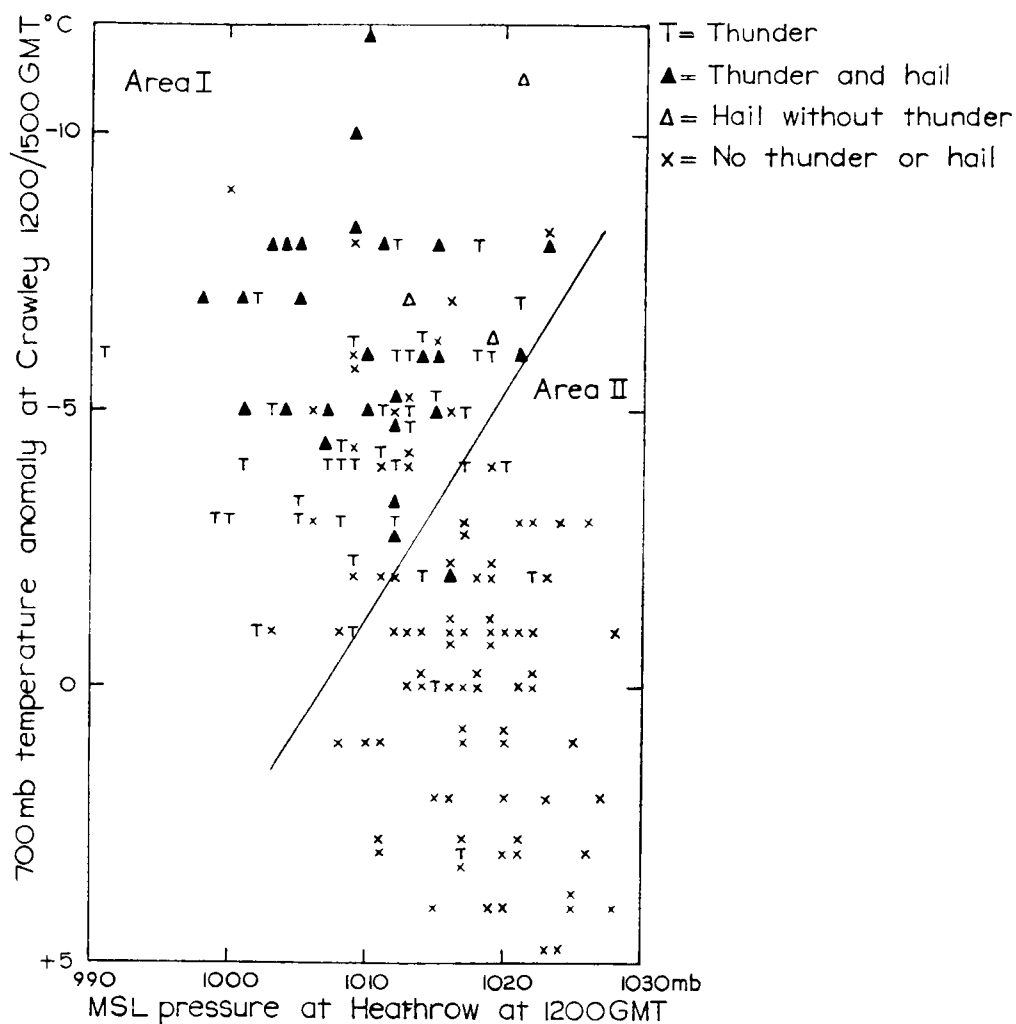


FIGURE 4—THUNDER AND HAIL IN SOUTH-EAST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

Areas I and II are the same areas as in Figure 1.

with 'no thunder', representing 74 per cent of all occasions of 'no thunder' and 99 per cent with 'no hail', representing 58 per cent of all occasions of 'no hail'. If the diagram were used to indicate thunder or 'no thunder', a skill score of 0.62 would be obtained. For an indication of hail or 'no hail', a skill score of 0.33 would be obtained.

Many of the occasions of thunder without hail occurred with relatively high 700 mb temperatures, suggesting that hail may have formed and melted before reaching the ground. Of all occasions of thunder, 41 per cent were accompanied by hail, but of the 15 occasions of thunder when the height of the freezing-level above the ground at Crawley was 207 decametres or more, only two were associated with hail. Mason⁷ deduced that with the melting-level at 200 decametres,

solid ice particles would need to be of initial radius greater than 2.5 mm and graupel pellets (density 0.3 g/cm^3) at least twice as large in order to retain an unmelted core during the downward journey. If the height of the freezing-level above the ground could be forecast and hail were forecast only when the height was less than 207 decametres, the skill score would be improved from 0.33 to 0.36.

On all but two occasions, reports of thunder were associated with negative temperature anomalies. On all occasions of hail, the negative temperature anomaly was 2°C or more.

Sunshine.—A diagram was plotted (Figure 5) of the 700 mb anomaly against mean sea level pressure, with figure entries representing the average

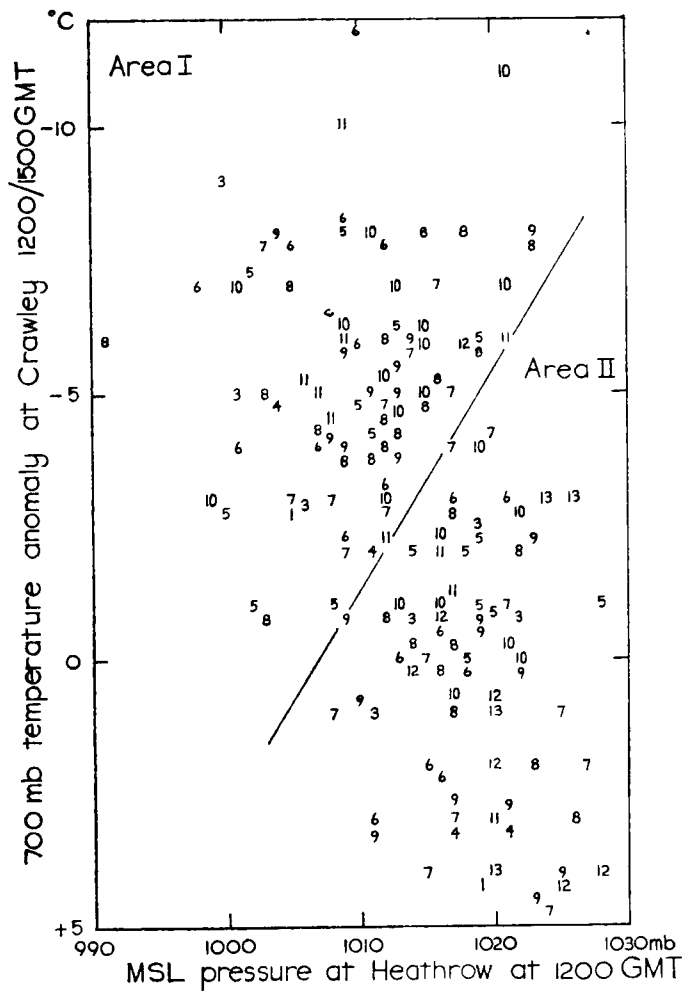


FIGURE 5—AVERAGE DURATION OF SUNSHINE FOR SEVEN STATIONS IN SOUTH-EAST ENGLAND FOR EACH INDIVIDUAL DAY ASSOCIATED WITH SURFACE PRESSURE AND THE 700 MB TEMPERATURE ANOMALY

Areas I and II are the same areas as in Figure 1.

duration of sunshine in hours for seven of the stations in south-east England for each day examined. If the diagram is divided into areas I and II, representing generally high and low shower activity respectively, the high and low values of sunshine duration appear to be scattered at random in both areas and there is no evidence of an association between the intensity of shower activity and the duration of sunshine. It is clear that a substantial amount of morning sunshine, as implied by the large total durations, is no bar to a showery afternoon.

Association with 1000–500 mb thickness and surface pressure.—The 1000–500 mb thickness anomaly at Crawley for 1200 GMT (1500 GMT before 1957) was extracted for the period 1952–64; for 1952 Larkhill was used. Anomalies were measured from the 5-day mean 1000–500 mb thickness values for Crawley given in Table IV.

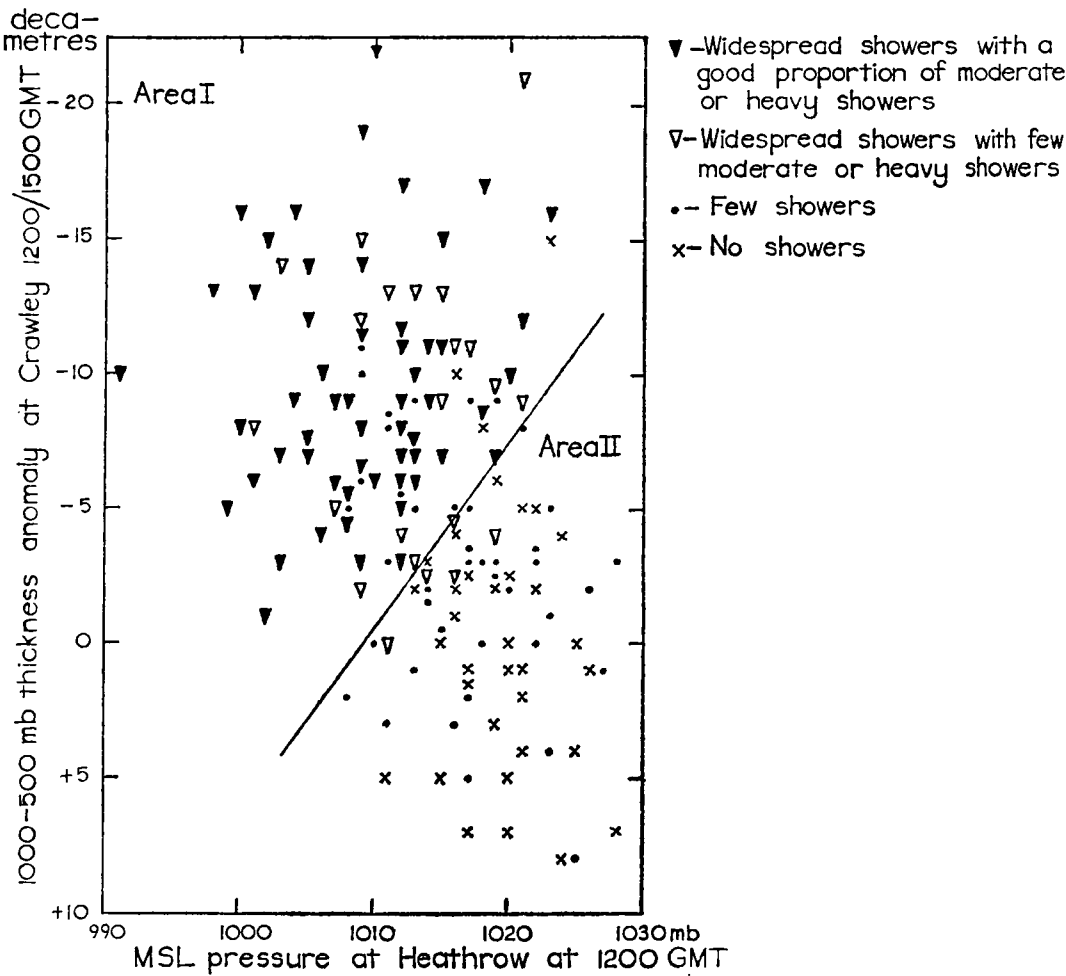


FIGURE 6—SHOWER ACTIVITY IN SOUTH-EAST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

The line divides the diagram into area I containing most of the occasions of widespread showers and area II containing most of the occasions of few or no showers.

TABLE IV—FIVE-DAY MEAN 1000–500 MB THICKNESS AT CRAWLEY* IN DECAMETRES

Period	Mean	Period	Mean	Period	Mean
1–5 May	543	30 June – 4 July	553	29 Aug. – 2 Sept.	554
6–10	544	5–9 July	554	3–7 Sept.	553
11–15	545	10–14	555	8–12	552
16–20	546	15–19	556	13–17	552
21–25	547	20–24	556	18–22	551
26–30	547	25–29	556	23–27	551
31 May – 4 June	548	30 July – 3 Aug.	556	28 Sept. – 2 Oct.	550
5–9 June	549	4–8 Aug.	556		
10–14	550	9–13	556		
15–19	551	14–18	556		
20–24	552	19–23	555		
25–29	553	24–28	555		

*Obtained from 5-year monthly means⁸ for the period 1951–55 (Larkhill 1951–52, Crawley 1953–55).

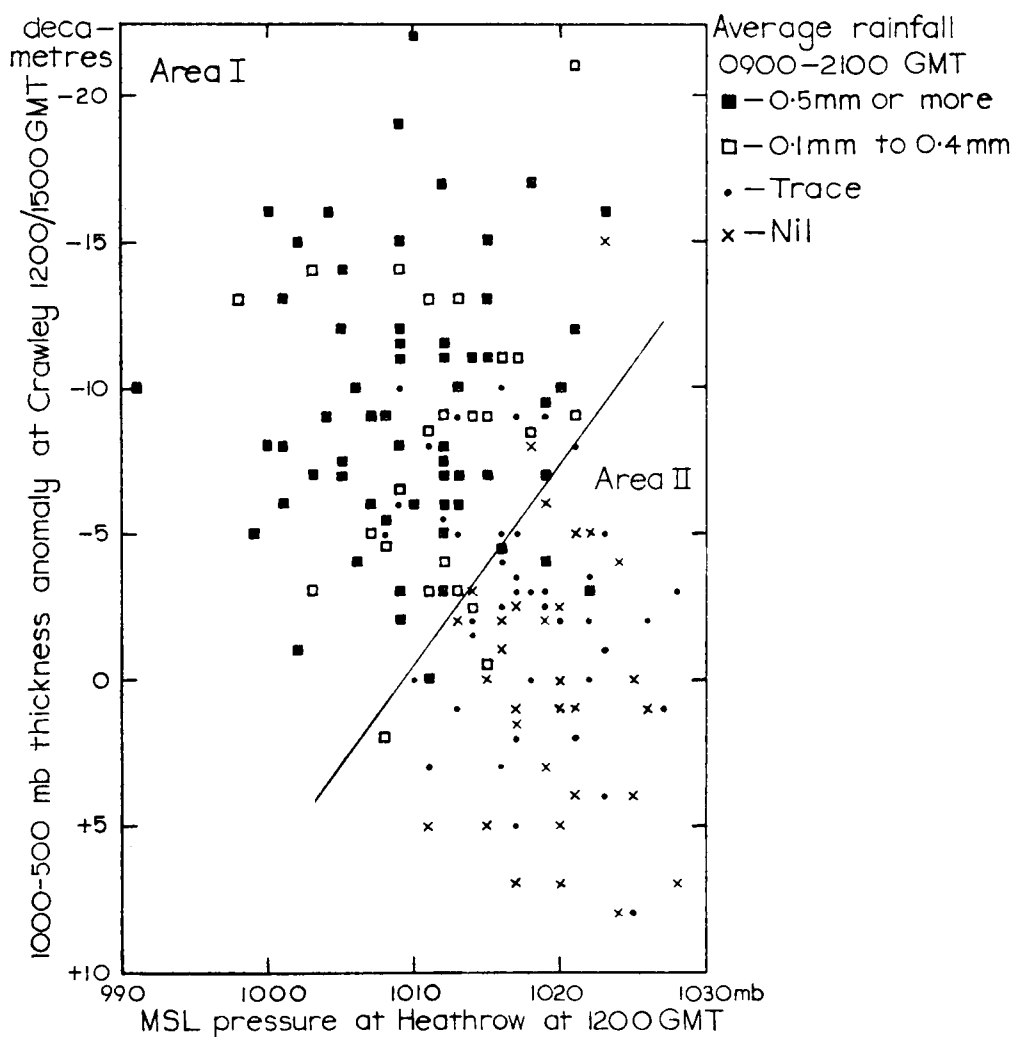


FIGURE 7—AVERAGE RAINFALL FOR EIGHT STATIONS IN SOUTH-EAST ENGLAND FOR EACH INDIVIDUAL DAY ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

Areas I and II are the same areas as in Figure 6.

Analyses were carried out with the 1000–500 mb thickness anomaly in place of the 700 mb temperature anomaly and statistics were extracted to construct Figures 6, 7 and 8. The corresponding skill scores are shown in Table V (page 279).

An analysis was also carried out with the 1000–700 mb thickness anomaly in place of the 700 mb temperature anomaly and similar statistics extracted. The corresponding skill scores are also shown in Table V.

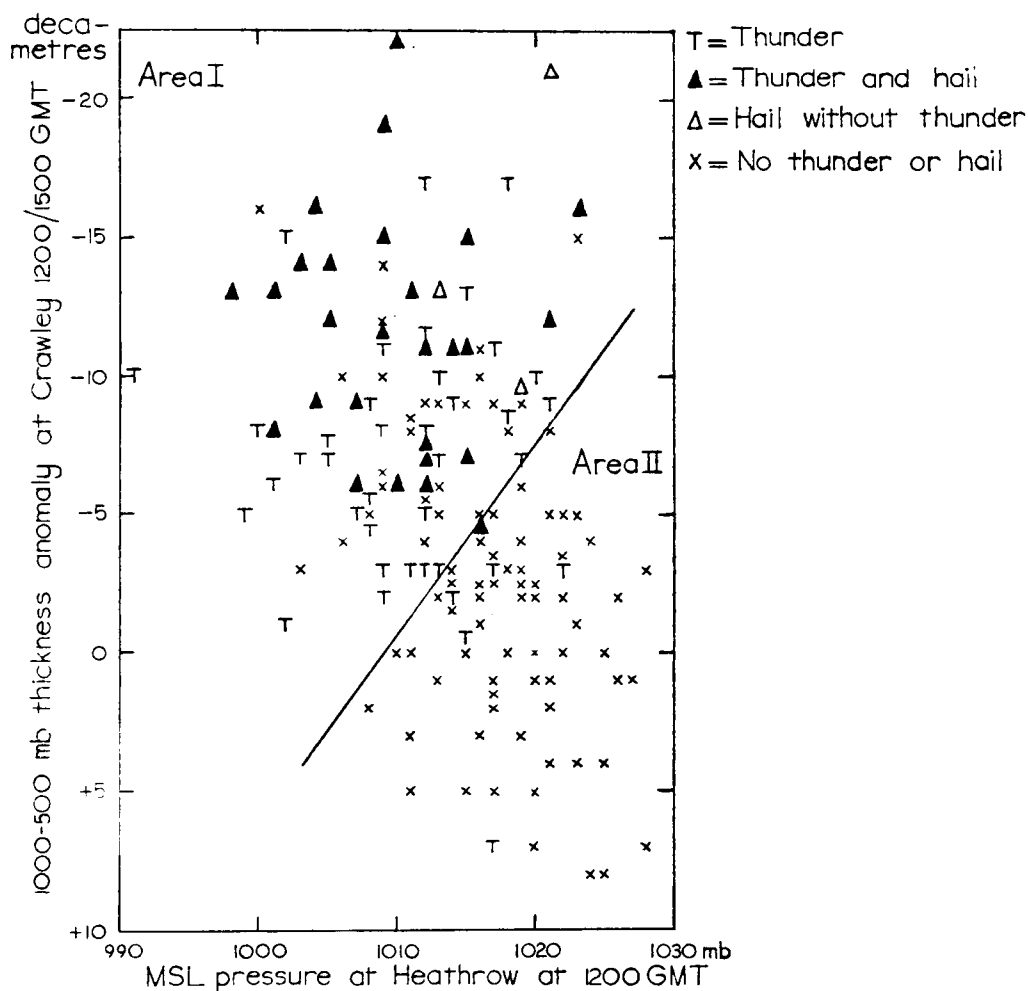


FIGURE 8—THUNDER AND HAIL IN SOUTH-EAST ENGLAND ASSOCIATED WITH SURFACE PRESSURE AND THE 1000–500 MB THICKNESS ANOMALY

Areas I and II are the same areas as in Figure 6.

Association with the Boyden instability index.—The instability index proposed by Boyden¹ was calculated for the Crawley 1200 GMT ascents (1500 GMT before 1957). For 1952, Larkhill was used. The formula for the index (I) was

$$I = \bar{z} - T - 200$$

where \bar{z} = 1000–700 mb thickness in decametres,
 T = 700 mb temperature in °C.

Rain showers.—Figure 9 shows the distribution of the instability index and the frequency of days on which the various intensities of shower activity occurred. Of the occasions with an index of 94 or more, 79 per cent were associated with widespread showers (classes *A* and *B*), representing 87 per cent of all occasions of widespread showers. Of the occasions with an index of 93 or less, 85 per cent were associated with few showers or no showers (classes *C* and *D*), representing 77 per cent of all occasions of few showers or no showers. Assuming that the index could be forecast and was used to forecast either widespread showers or few showers/no showers, a skill score of 0.64 would be obtained.

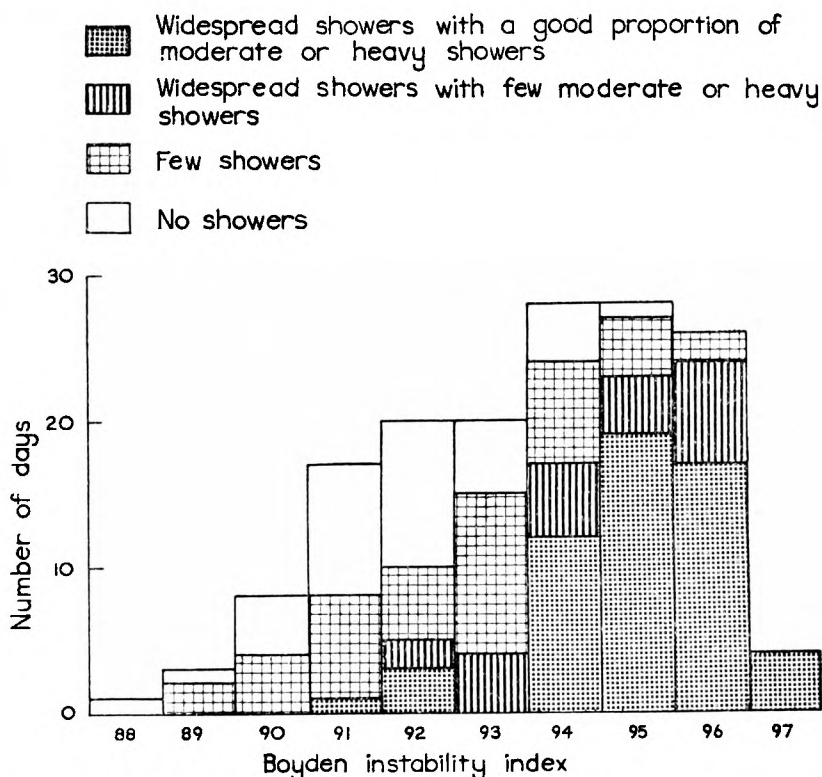


FIGURE 9—FREQUENCY OF DAYS WITH SHOWERS FOR EACH VALUE OF THE BOYDEN INSTABILITY INDEX

Rainfall amount.—Figure 10 shows the frequency of days on which various average rainfall amounts occurred. Of the occasions with an index of 94 or more, 85 per cent were associated with an average rainfall of 0.1 mm or more, representing 88 per cent of all occasions of 0.1 mm or more. Of the occasions with an index of 93 or less, 85 per cent were associated with less than 0.1 mm, representing 82 per cent of all occasions of less than 0.1 mm. If the index were used to indicate either 0.1 mm or more, or less than 0.1 mm, a skill score of 0.70 would be obtained.

Of the occasions with an index of 94 or more, 64 per cent were associated with 0.5 mm or more, representing 93 per cent of all occasions of 0.5 mm or more. Of the occasions with an index of 93 or less, 94 per cent were associated with less than 0.5 mm, representing 68 per cent of all occasions of less than 0.5 mm. If the index were used to indicate either 0.5 mm or more, or less than 0.5 mm, a skill score of 0.56 would be obtained.

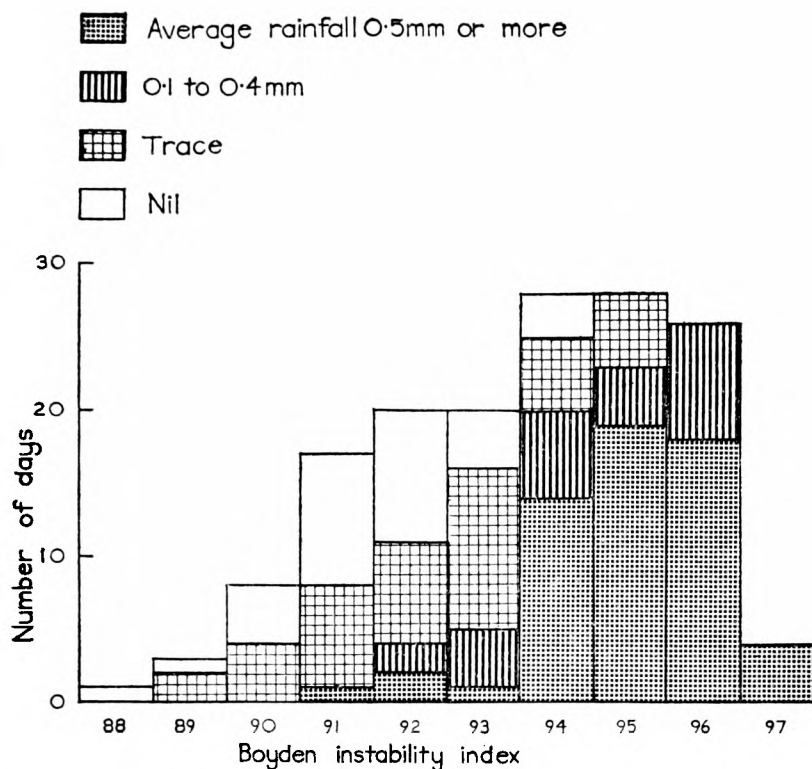


FIGURE 10—FREQUENCY OF DAYS WITH RAIN FOR EACH VALUE OF THE BOYDEN INSTABILITY INDEX

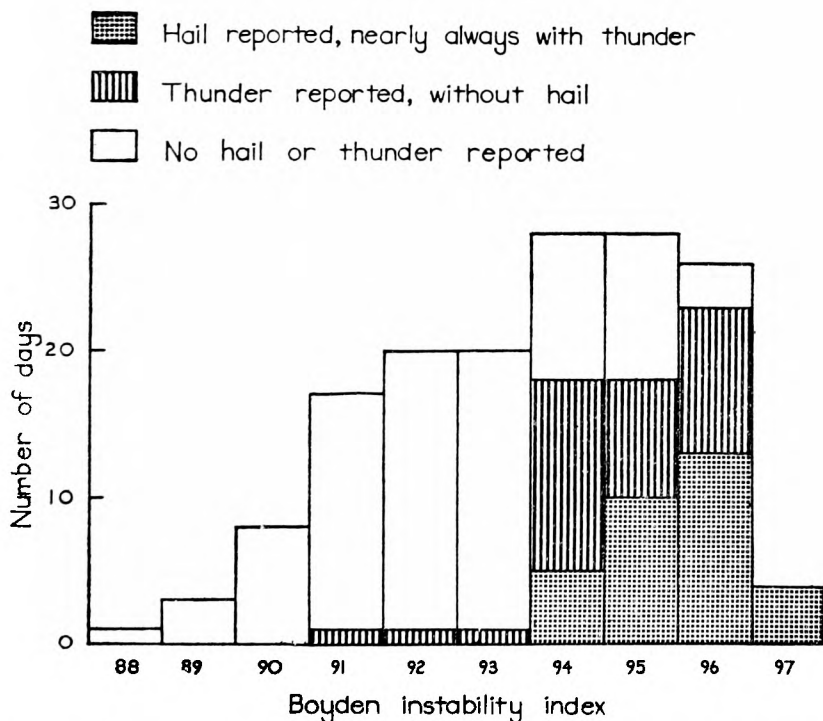


FIGURE 11—FREQUENCY OF DAYS WITH HAIL OR THUNDER FOR EACH VALUE OF THE BOYDEN INSTABILITY INDEX

Thunder and hail.—Figure 11 shows the frequency of days on which hail or thunder was reported. Of the occasions with an index of 94 or more, 73 per cent were associated with thunder, representing 96 per cent of all occasions of thunder and 35 per cent with hail, representing all occasions of hail. Of the occasions with an index of 93 or less, 96 per cent were associated with 'no thunder', representing 74 per cent of all occasions of 'no thunder' and 100 per cent with 'no hail' representing 55 per cent of all occasions of 'no hail'. If the index were used to indicate thunder or 'no thunder', a skill score of 0.67 would be obtained. For an indication of hail or 'no hail', a skill score of 0.32 would be obtained. If the height of the freezing-level above the ground could be forecast and hail was forecast only when the height was less than 207 decametres, the skill score would be improved from 0.32 to 0.38.

Using similar data for 1960 to 1962, but including all non-frontal situations, Boyden¹ found that 49 per cent of occasions with an index of 94 or more were associated with thunder compared with 73 per cent in the present investigation. The difference is clearly due to the relatively high probability of thunder in airstreams from the north-west quarter to which the present work is restricted.

Association with the Rackliff and Jefferson instability indices.—Analyses similar to that for the Boyden instability index were carried out for the Rackliff instability index,² the Jefferson instability index³ and the modified Jefferson index.⁴ The indices are defined as follows:

$$\text{Rackliff index } (\Delta T) = \theta_{w900} - T_{500}$$

$$\text{Jefferson index } (T_J) = 1.6\theta_{w900} - T_{500} - 11$$

$$\text{Modified Jefferson index } (T_{mJ}) = 1.6\theta_{w900} - T_{500} - \frac{1}{2}T_{d700} - 8$$

where θ_{w900} = 900 mb wet-bulb potential temperature in °C,

T_{500} = 500 mb dry-bulb temperature in °C,

T_{d700} = dew-point depression at 700 mb in °C.

The corresponding skill scores and critical values of the indices are given in Table V.

The effect of warm fronts from the west.— On some occasions the midday ascent at Crawley was not representative of conditions later in the day owing to the arrival of overrunning warm air associated with the rapid approach of a warm front from the west, resulting in the damping down of shower activity. The seven dots and one cross within area I of Figure 2 represent occasions when the average rainfall from showers was only a trace or less. On four of these occasions, a warm front moved quickly eastwards, reaching 5°W by 2359 GMT and on one occasion a warm front reached 10°W. Of the 47 occasions during the 13 years when a warm front reached 10°W by 2359 GMT, 72 per cent were associated with an average rainfall of a trace or less. Of the 15 occasions when a warm front reached 5°W, 87 per cent were associated with a trace or less.

The relative usefulness of the predictors.— Assuming that the predictors can be forecast, their relative usefulness in forecasting showers activity, rainfall amount, thunder and hail can be assessed by a comparison of skill scores. Table V shows the skill scores obtained by the predictions already discussed and also for the 1000–700 mb thickness anomaly used with surface pressure.

TABLE V—A COMPARISON OF SKILL SCORES

Predictors	Shower activity	Rainfall (limit 0.1 mm)	Rainfall (limit 0.5 mm)	Thunder	Hail	Hail*
700 mb temperature anomaly and surface pressure	0.77	0.78	0.58	0.62	0.33	0.36
1000–500 mb thickness anomaly and surface pressure	0.73	0.74	0.53	0.56	0.28	0.31
1000–700 mb thickness anomaly and surface pressure	0.68	0.71	0.47	0.48	0.23	0.27
Boyden instability index	0.64	0.70	0.56	0.67	0.32	0.38
(critical values)	(93/94)	(93/94)	(93/94)	(93/94)	(93/94)	(93/94)
Rackliff instability index	0.69	0.73	0.64	0.62	0.45	0.49
(critical values)	(28/29)	(28/29)	(30/31)	(29/30)	(29/30)	(29/30)
Jefferson instability index	0.63	0.71	0.59	0.59	0.45	0.52
(critical values)	(22/23)	(22/23)	(25/26)	(25/26)	(25/26)	(25/26)
Modified Jefferson instability index	0.65	0.69	0.64	0.61	0.47	0.54
(critical values)	(20/21)	(20/21)	(22/23)	(24/25)	(24/25)	(24/25)

*Including freezing-level as a predictor.

The 700 mb temperature predictor gives the highest scores in general but not for forecasting hail. The instability indices and the 700 mb temperature predictor show similar degrees of success in forecasting the higher rainfall amounts and thunder. The 1000–700 mb thickness predictor is rather less successful than the 1000–500 mb thickness predictor. The highest scores for the forecasting of hail are obtained by the Rackliff, Jefferson and modified Jefferson indices. However, which predictor is to be preferred depends largely on which is easiest to forecast.

Conclusions.—This investigation was concerned with polar airstreams from the north-west quarter affecting south-east England in summertime and was restricted to days when no fronts were situated over south-east England. Widespread showers are likely if the associated depression is situated over Scotland or the North Sea at midday. Few showers are likely if the depression is over the Norwegian Sea or the Arctic. If the depression is situated to the north of Scotland or over Scandinavia, widespread showers are just as likely as few showers or no showers.

Widespread showers with thunder are likely if a major surface trough moves across England. Widespread showers are also likely if a minor perturbation moves across England or if the isobars are uniformly cyclonic. Few showers or no showers are likely if the isobars are anticyclonic. Few showers are likely if a warm front from the west is expected to reach 5°W by 2359 GMT.

An indication of the intensity of shower activity, rainfall amount and the likelihood of thunder or hail can be obtained from the midday values of (1) the 700 mb temperature anomaly at Crawley and the surface pressure at Heathrow, (2) the 1000–500 mb thickness anomaly at Crawley and the surface pressure at Heathrow, (3) the Boyden instability index, (4) the Rackliff instability index, (5) the Jefferson instability index and (6) the modified Jefferson instability index. The indication of hail can be improved by the use of the height of the freezing-level above the ground as a further predictor.

The relative usefulness of the predictors has been evaluated; which is to be preferred in forecasting depends largely on how successfully each can be forecast.

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551.508.77

A STANDARD HEATER FOR RECORDING RAIN-GAUGES

By A. L. MAIDENS

The provision of a source of heat within a rain-gauge can be intended either for the melting of hail or snow, or for ensuring continuity of operation of the gauge during occasions of frost. To achieve the former, the amount of heat necessary to thaw frozen precipitation can be considerable and is often beyond the means of the available energy which can be conveniently provided. Moreover it is debatable whether a rain-gauge is in fact the best means of obtaining a representative sample of snowfall.

Heat is also required within a recording rain-gauge to ensure that the recording mechanism is free to operate should rain occur during or immediately after a spell of frost, when the mechanism might otherwise be frozen. A limited amount of heat, suitably applied, will then suffice to ensure the immediate readiness of the gauge to record the first rainfall.

No standard form of heater has hitherto existed for Meteorological Office rain-gauges, although small 15- or 25-watt lamps have been provided for use where mains electrical supplies can be made available at the rain-gauge site. Alternatively it has been necessary to employ night-lights or similar forms of combustion heating. Outside the Office, various types of electrical heating have been individually designed, of which that described by Rodda* is of special interest.

In a new system which will shortly be available as a complete kit for incorporation within the Meteorological Office tilting-siphon rain recorder, the lamps are replaced by a robust and flexible heater strip, of almost unlimited operating life, which can be easily installed adjacent to the recording mechanism and float chamber. This heater operates on a 24-volt supply which can be provided either from the mains supply through a suitable transformer or from accumulators. This low voltage has been chosen on the grounds of safety.

The heater unit, which provides an output of 15 watts, is controlled by a thermostat. In this way the amount of power required to maintain the internal temperature at a value just above the freezing-point is kept to a minimum and there is no risk of overheating, with consequent evaporation losses.

As a further step towards power conservation, the complete kit includes easily attachable insulating material, tailored to cover the internal surfaces of the funnel, walls and base of the instrument compartment. In addition to

*RODDA, J. C. A note on the operation of rain-recorders during cold weather. *Met. Mag., London*, **92**, 1963, p. 335.

reducing heat losses, this insulation should itself reduce evaporation in summer. The kit will not only be available as a standard item of supply within the Meteorological Office but will be placed on the market for direct purchase.

An assembly has been tested in an ice chamber at the Meteorological Office, Bracknell. This environmental temperature averaged -10°C and surrounded the whole gauge, including those parts normally buried within the ground and hence protected to some degree from low temperatures. The test continued for one month during which time the internal temperature remained at between $+1$ and $+4^{\circ}\text{C}$. Under these severe conditions the thermostat remained closed for the bulk of the time and electrical consumption was thus at the maximum level of 15 ampere-hours per day. At this rate, for continuous frost protection, a pair of small, car accumulators would require recharging at intervals of four days. Under more typical frosty conditions a much lower consumption could be anticipated but as the need for recharging will depend on the duration and severity of the frost and the heat losses due to wind, conditions will vary from site to site.

Although the present design is intended specifically for the Meteorological Office tilting-siphon rain recorder, only small changes in the shaping of the insulating material will be required to adapt the system to most other types of rain-gauges. The option of employing either mains supplies or accumulators should widen the circumstances under which electrical power may be conveniently employed for frost protection.

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METEOROLOGY AT THE 1965 WORLD GLIDING CHAMPIONSHIPS

By C. E. WALLINGTON

In May 1965, glider teams from 28 countries came to South Cerney, Gloucestershire, to compete in the 1965 World Gliding Championships. As weather is one of the most vital factors in a gliding championship a temporary meteorological office was set up at the airfield to provide a service for the organizers and the visiting teams.

The forecaster's most important job at a championship is to advise on the suitability of the weather for flying tasks which are set, if possible, on each day. These flying tasks are contests to see who can fly the furthest or fastest, although the accent nowadays is on racing rather than distance flying. A race may be to a distant goal or around a closed circuit (mostly triangular) the distance usually being between about 100 and 300 kilometres. Convective upcurrents commonly called 'thermals' are used by glider pilots to remain airborne and such convection need not be deep. A clear sky with light winds, little or no smoke haze and a low-level dry-adiabatic (or superadiabatic) layer from ground level to about 2000 feet or just over will usually provide enough thermals for top-class pilots to remain airborne for a long time, and if the depth of the convective layer extends to 4000 or 5000 feet these pilots can usually cover the distance around a course at average speeds of between 30 and 50 knots.

Gliders can fly at speeds up to between 100 and 120 knots, so provided that not too much time is used in climbing in thermals, a pilot can make appreciable headway into wind when necessary.

Early each morning the three forecasters at the championships concentrated their efforts on meso-scale analysis and prediction of cloud, temperature,

visibility and wind structure over England and Wales. Normal routine observations are not enough for such analyses so reconnaissance and temperature sounding flights were carried out and assistants made frequent pilot-balloon observations.

As soon as the day's task was decided, details of the local and route forecasts were sketched on a set of blackboards and 160 copies of these forecasts were duplicated for pilots, team managers and the Press. The general briefing that followed was conducted in English, French and German with the help of experienced gliding forecasters from France and Germany (see Plate II).

On racing days the next duty of the organization was to launch the 86 competing pilots as quickly as possible when local conditions were just suitable, and as conditions were only marginally suitable on many days, the timing was critical. A fairly elaborate plan was put into effect. Two gliders, one with a forecaster on board, were flown continuously from mid-morning until conditions were suitable. The object of these flights was to test the characteristics of low-level turbulence and thermals and relate these to the local temperature sounding and surface temperature. Another forecaster remained in the office to keep a constant watch on the surface temperature changes, pilot-balloon observations and synoptic information, while the third forecaster liaised with the Championship Director at the launching point or made quick Chipmunk reconnaissance flights if necessary to view cloud structure further upwind than could be seen from the ground. These forecasters and the flying control organization were all linked together by 'walkie-talkie' radios. When conditions appeared to be suitable and safe the Director gave a signal for launching to start, whereupon all the gliders could be launched within 15 minutes. Although this procedure may appear elaborate, it was apparent that several contest days would have been lost or mismanaged without it.

Forecasting for a gliding championship brings the forecasters concerned into closer contact with the weather and the users of the meteorological service than is ever achieved in any other application of meteorology. Obligatory meso-scale analysis reveals coherent structures that are often missed in other types of forecasting duties; flight reconnaissance by forecasters adds a valuable dimension to their paper-work forecasting and, at South Cerney, foreign meteorologists who accompanied a number of teams and glider pilots (who amassed 2500 launches and flew 50,000 miles during the two-week contest period) were keen to discuss meteorology from morn till night.

METEOROLOGICAL OFFICE NEWS

Secretary, Meteorological Office

Mr. W. J. B. Crotch, Secretary of the Meteorological Office since April 1957 retired from established civil service on 30 June 1965 after a career which began in the academic world. He graduated with first class honours in English from London University (King's College) in 1922 and after some years of post-graduate work he joined the staff of the London School of Economics in 1927. There he remained, first as a lecturer and then as one of the administrative staff, until 1941 when he joined the Air Ministry as an Administrative Officer. His subsequent experience ranged over a wide area and included service in the Establishment, Finance and Secretarial Divisions, in Organization and Methods and in Civil Training as well as a year with the United States Army Air Force

at the Headquarters of the 3rd Air Force, at Ruislip. He was promoted Assistant Secretary in 1955 and became the first Secretary of the Meteorological Office in April 1957.

At an informal gathering at Bracknell Headquarters in June a tribute to his work in the Office was paid by the Director-General who wished him well in his new unestablished appointment with the Navy Department at Bath.

The new Secretary of the Meteorological Office is Mr. B. M. Day. After commissioned service in the Royal Artillery from 1947 to 1948 Mr. Day graduated with honours from the London School of Economics in 1950. He joined the Air Ministry in the following year as an Assistant Principal and served in the Finance and Secretarial Divisions and as Private Secretary to the Air Member for Supply and Organization. In 1956 he was promoted to the grade of Principal and was seconded to the Cabinet Office for two years from 1959. During this period he was Secretary General of the Sierra Leone Constitutional Conference. On returning to the Air Ministry he served in the Central Finance Division and in 1963 he attended the Fourth Congress of the World Meteorological Organization as the financial adviser to the United Kingdom delegation. Mr. Day has now been promoted Assistant Secretary and we welcome him to his new appointment in the Meteorological Office.

NOTES AND NEWS

Meteorology in the University of Reading

On retirement from the Meteorological Office, Dr. R. C. Sutcliffe has become Professor of Meteorology in the University of Reading. This appointment marks the creation by the University of a new department which it is planned will undertake undergraduate and graduate teaching as well as research and will need to expand to a considerable size.

The proximity of the University to the Meteorological Office at Bracknell would point to a special relationship between the two institutions and Professor Sutcliffe has this circumstance much in mind. The *Meteorological Magazine* hopes soon to be able to publish a fuller account of this important new development in university meteorology.

551.511:551.513.1:551.521

Address by Professor E. H. Palmén

At the invitation of the Director-General, a special lecture was given at Bracknell on 10 May 1965 by Professor E. H. Palmén of Finland. Although the first 25 years of his academic career were spent at the Finnish Institute of Marine Research, it is as a meteorologist that the Professor is perhaps better known internationally. Over the last 20 years his studies have ranged over such varied subjects as tropical hurricanes, evaporation and, of course, atmospheric meridional circulations and transfers. His choice of subject on this occasion was 'The atmospheric heat budget and general circulation'.

The atmospheric heat budget is often investigated from two different aspects: either by a consideration of the air currents and the way in which they redistribute quantities of heat, or by a consideration of the excesses (and deficits) of heating over the latitudes, from which can be deduced the heat flux required to maintain the observed temperature distribution.

Looking at the second of these two methods, the three ways in which significant heating of the atmosphere can be achieved are by a net radiation input, by

heat exchange at the boundary interface and by the release of latent heat due to water state changes. An equivalent statement holds for the earth. London (1957) considered the radiative heating process for the combined earth-atmosphere system for both summer and winter. Assuming the net heating of the earth at these two solstices to be approximately zero he was able to derive estimates of the atmospheric meridional heat flux required to maintain the observed temperature distribution. He found, in addition to the need of a poleward flux of heat that an unrealistically large heat flux across the equator was also implied. Such an anomaly arises largely as a result of the invalid assumption that the earth's heat storage in winter and summer is small; it is known that the ocean temperatures in the northern hemisphere reach a minimum around 1 March and a maximum around 1 September. More than 60 per cent of the northern hemisphere surface is water-covered and it requires a 200-metre layer to cool through only 0.85°C during the three winter months for the cross-equator flux implied by London's results to be reduced to zero. This underlines the importance of the role played by the oceans in the heat budget of the atmosphere. To avoid the difficulty it is necessary to formulate a heat balance equation for the atmosphere alone; this requires knowledge of the heat transfer between earth and atmosphere. Budyko (1963) has derived mean values of this transfer which, together with estimates of atmospheric radiative heating and of latent-heat release, enable us to formulate a heat budget of the atmosphere, together with the associated heat flux.

Considering now the first aspect, estimates of the meridional heat flux can be made directly from available data. Three different atmospheric motions contribute significantly here—mean meridional circulation of the Hadley type, the semi-permanent standing waves and the synoptic-scale transient eddies. Many papers have been written on their respective roles in the transport of the relevant meteorological parameters and each of the three types of motion can be shown to play an important part in the redistribution of particular elements—the poleward transport of sensible heat being generally associated with the Hadley circulation in low latitudes while the standing-wave and transient eddy motions are the more influential in higher latitudes.

It is interesting to compare the implied flux of the heat excess/deficit estimates with the directly measured flux. Incorporation of Budyko's estimates into the former leads to a meridional heat flux picture which is quite similar to that derived by the latter method.

If we are to appreciate fully the heat budget and fluxes derived then it is necessary to consider also the manner in which vertical motions redistribute heat within the atmosphere. Near the equator the vertical limb of the Hadley circulation is seen to carry heat upwards, though vigorous small-scale convective activity is considered to be the major factor in diffusing heat from the surface.

Polewards of 30°N , winter convective activity is usually limited to the lower half of the troposphere and to the sea areas; cyclonic activity penetrates a greater depth of the atmosphere and though synoptic-scale eddies are not usually associated with downward transfer of heat, schematic vertical velocity fields in the disturbed westerly belt have been found to suggest a positive correlation between temperature and descending motion. From an appropriate vertical integration based on this positive correlation it is possible to derive the rate of conversion of potential energy to kinetic energy in the atmosphere; this is found

to be of the order of four watts per square metre, a value which agrees well with independent estimates of the compensating frictional dissipation of kinetic energy.

To make such a comprehensive review of the problem of the atmospheric heat budget within the short time of a lecture was indeed an achievement, the appreciation of which was shown by the audience.

D. B. SHAW

REVIEW

Physics of the marine atmosphere by H. U. Roll. 9½ in × 6½ in, pp. viii + 426, illus., Academic Press Inc., 111 Fifth Avenue, New York 10003, 1965. Price: £5 7s. 6d.

In the preface Dr. Roll states "although a number of books exist that treat marine meteorology as an applied science I doubt whether there is any book available that considers the subject as a pure science," and accordingly sets out to fill one of the remaining gaps in meteorological literature.

In Part I the author, after considering whether there should be only one meteorology to deal with the atmosphere as a whole, argues that there is a sufficiently large number of meteorological phenomena which are closely related to, or dependent upon, the sea surface and which do not occur over the land, to warrant a separate treatment. In the present book the marine atmosphere is defined as that part of the atmosphere which has the sea surface as its lower boundary and which receives its peculiar characteristics from interaction with the sea, and the author restricts himself to the description of atmospheric processes of small and medium scale only, leaving discussion of large-scale phenomena over the oceans to be undertaken elsewhere.

In Part II the particular difficulties connected with meteorological measurements at sea, the bases and procedures which are available for executing such measurements, and the instruments and methods which are used for making routine measurements at sea are discussed.

Part III deals with the subject of atmospheric nuclei over the oceans, their concentration, size and chemical composition and their interrelation with meteorological elements and phenomena. A brief description of atmospheric electricity and radio-activity is included for the sake of completeness.

Part IV which discusses the flow characteristics of the marine atmosphere is probably the most valuable section in the book. This emphasizes the differences between flow over land and sea, and in particular highlights the difficulties experienced in dealing with flow over a surface generally distorted by a large variety of ocean waves, all different in size, shape and velocity as well as being subject to continuous and irregular changes, and which, with increasing wind speed, tends to disintegrate into sea spray and foam. After consideration of the essentials of the sea surface which may or may not be related to the wind structure, the author proceeds to a discussion of the wind field above and around the ocean waves, the effect upon the wind profile of thermal stratification over the sea, the mean stress at the sea surface, the drag coefficient, the variance of horizontal and vertical wind fluctuations, and the diurnal, annual and aperiodic variations of the wind.

Part V deals with the thermodynamic processes in the marine atmosphere resulting from the fact that the temperature and moisture contents of the lower layers of the air over the sea are influenced by the sea surface. Factors affecting the sea surface temperature, horizontal variations of sea surface temperature, diurnal, annual and non-periodic variations of the sea surface temperature, and air effects on the temperature and moisture fields in the first few metres are discussed in some detail as are also the modification of cold or warm air masses moving over warm or cold seas.

This book which is the seventh in the International Geophysical series edited by J. Van Mieghem is mainly concerned with maritime boundary problems and with one exception the author has confined himself to a treatment of the marine atmosphere in the lowest 1500 metres above the sea. This exception, the discussion of oceanic cumulonimbus cloud in part V, appears to be somewhat out of place in the present monograph and although of interest should not in the opinion of the reviewer have been included.

Dr. Roll has performed a valuable service in gathering together into a connected and well-written account of the results of about 550 studies on marine meteorology, mostly written within the last decade, which up to now have been scattered in many different and sometimes non-meteorological journals in many countries. The production is excellent and the reviewer noticed no misprints.

R. FROST

HONOURS

The following awards were announced in the Birthday Honours List in June 1965:

C.B.E.

Mr. B. C. V. Oddie, Deputy Director (Central Services), Meteorological Office.

I.S.O.

Mr. C. W. G. Daking, Assistant Director (Defence and International), Meteorological Office.

M.B.E.

Mr. F. J. Parsons, Auxiliary Observer, Ross-on-Wye.

AWARD

We have great pleasure in recording that Mr. C. E. Wallington, Principal Scientific Officer and Superintendent of the Meteorological Office Porton, has recently been awarded the OSTIV Plaque for 1965. The President of the Organisation Scientifique et Technique Internationale du Vol à Voile (OSTIV), Mr. L. A. de Lange, presented the plaque at the opening ceremony of the Xth OSTIV Congress held at South Cerney on 4 June 1965, saying that it was in recognition of Mr. Wallington's services to gliding, including his textbook *Meteorology for glider pilots*, his researches into the sea-breeze front and his meteorological advice at many gliding meetings in various parts of the world since 1953.

This award is made for "the most noteworthy scientific contribution to soaring flight" and Mr. Wallington is the fourth recipient of the plaque since it was instituted in 1958.

CORRIGENDUM

Meteorological Magazine, February 1965, p. 37: line 30 for "v is the frequency" read " $v/2\pi$ is the frequency"; line 37 for "underestimate of the calculated velocity" read "overestimate of the calculated velocity"—this is consistent with the view that it is unlikely that the disturbance was a stationary train of lee-waves.

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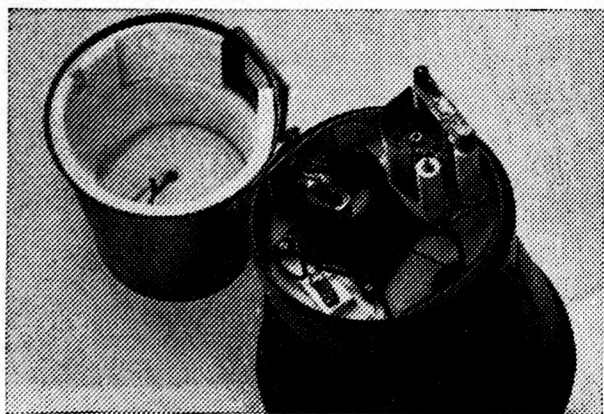
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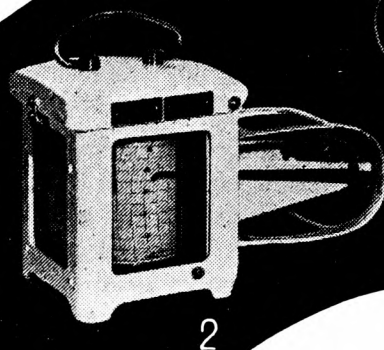
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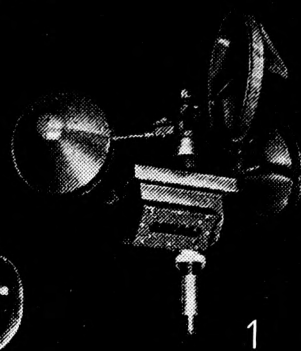
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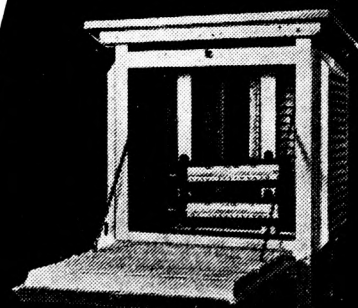
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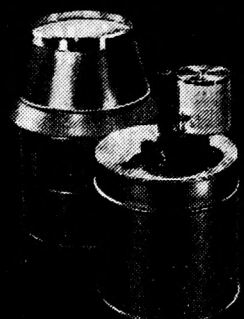
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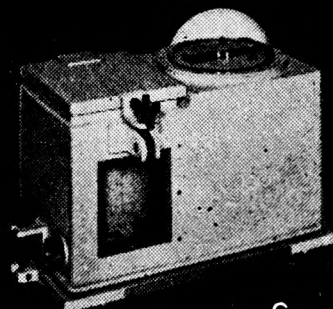
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Photograph by Sally Anne Thompson

PLATE II—DISCUSSION ON THE WEATHER SITUATION DURING THE WORLD GLIDING CHAMPIONSHIPS AT SOUTH CERNEY IN JUNE 1965

H.R.H. the Duke of Edinburgh discussing the weather with Mr. C. E. Wallington, Mr. Philip Wills (Chairman of the British Gliding Association) and Mrs. Ann Welch (Director of the Championships).

Special signs and symbols were used on the briefing boards to overcome the problem of briefing pilots of 28 nations (see page 281).

To face back cover

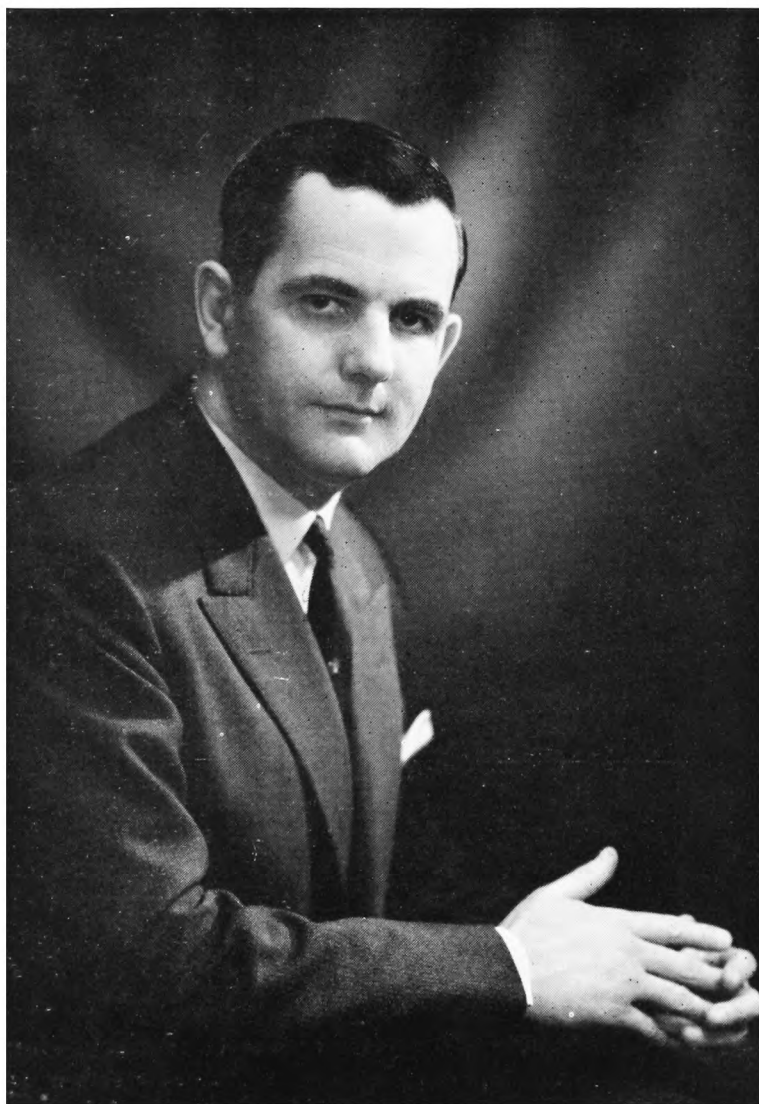


Photograph by H. H. Lamb

PLATE III—TORNADO DESTRUCTION OF TREES AT SHALFORD PARK, GUILDFORD,
SURREY

The tree nearest the camera was twisted off by a tornado at 1600 GMT on 26 April, 1965. The next stump only 8 metres away, seen—barkless and discoloured by age—in front of the white building, was plainly a relic of a similar event some decades before. The park is largely river meadows beside the River Wey where it cuts through the east-west line of the North Downs (100–150 metres high); the park lies in the southern entrance to the gap whose steep sides are at this point scarcely 800 metres apart. It is a likely place for twisting motions to be imparted to many airstreams; though abundant surface roughness (in the shape of trees, woods and lesser hills) probably tends to destroy these motions before they have travelled far.

The photograph was taken the morning after the event. Twentieth century technology is against the preservation of evidence of this kind. Within 4 days—before the first bright day for photography—all trace of these tornadoes had been removed by bulldozer and the site cleared.



Photograph by courtesy of Bassano & Vandyk Studios

PLATE I—DR. B. J. MASON, F.R.S.

THE METEOROLOGICAL MAGAZINE

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DIRECTOR-GENERAL OF THE METEOROLOGICAL OFFICE

Dr. B. J. Mason, F.R.S., has been appointed to succeed Sir Graham Sutton as Director-General of the Meteorological Office from 1 October 1965.

Dr. Mason comes of a Norfolk family and his early education was at Fakenham Grammar School. After commissioned service in the Radar Branch of the Royal Air Force during the war he graduated in 1947 at Nottingham University with first class honours in physics. The next year he joined the Department of Meteorology at the Imperial College of Science and Technology, University of London, where he quickly became immersed in the study of microphysical processes in clouds. During this period he found a fruitful collaborator in Dr. F. H. Ludlam, whose interests lay more in the macrophysical aspects of cloud formation. The outstanding characteristic of Dr. Mason's work in this field is undoubtedly his skill in devising laboratory techniques for the investigation of problems of condensation and freezing in the atmosphere—for example, his use of the diffusion cloud chamber to ascertain the dependence of the structure of ice particles on temperature and supersaturation. His book, *The Physics of Clouds*, published in 1957, was quickly recognized as an authoritative and, in many respects, original contribution to meteorology. The same year he was appointed a Warren Research Fellow of the Royal Society and in 1960 his eminence in his chosen field led to his appointment to a newly-created Chair of Cloud Physics at Imperial College. Soon after this he evolved a novel theory of thunderstorm formation which is regarded by many as the best yet produced in this notoriously difficult field. Earlier this year he was elected to the Fellowship of the Royal Society at the early age of 41.

Dr. Mason is well known to the staff of the Meteorological Office and his long service with the Meteorological Research Committee has made him familiar with many of the problems of the professional worker. The Office will benefit greatly, not only from his knowledge and skill, but also from the drive and enthusiasm that he brings to all his interests.

A CLIMATIC SINGULARITY IN JUNE 1964 IN SOUTH-EAST ENGLAND

By E. N. LAWRENCE, B.Sc.

During the first 19 days of June 1964, a total of about four inches of rain, often with thunderstorms, was recorded at Kew (see Table I) and sufficient rain fell in south-east England to constitute one of the wettest Junes of this century. The period was characterized mainly by cyclonic pressure patterns in the region of the British Isles, while during the first 10 days or so pressure was rather high between Greenland and northern Norway; over Britain, the thermal wind (1000–500 mb) was predominantly south-westerly; during early June, the Azores anticyclone did not extend towards the British Isles until the second week and then only temporarily; from the 17th to 19th, the pressure pattern became anticyclonic in the Atlantic area west of Ireland, at least up to the 500 mb level. After the 19th the Azores 'high' persistently extended to the British Isles to assume a more normal synoptic pattern,¹ and to give mainly dry weather over south-east England for the remainder of June and early July. This anticyclonic period was in complete contrast to both the earlier part of June and to May, when the Azores anticyclone was weak and extended to the Atlantic area west of Ireland much less frequently than usual (cf. figures given by Newnham²).

This June 1964 rainfall pattern or sequence illustrates a well-known climatic singularity or weather episode, that is a period of weather around a particular time of the year which in some years is very well marked but which occurs to some extent in most years and is characteristic of an area. This June singularity is sometimes referred to as the 'European summer monsoon' because of the tendency for land-sea differential heating effects in May and June, as in the well-known Indian monsoon. The concept of weather singularities and other examples are further discussed elsewhere.^{3,4,5}

The main dates of the 'summer monsoon' in Europe are stated by Brooks³ as 1–21 June, and these dates are partly confirmed by Lamb,⁴ whose frequency curves for long spells of persistent weather show 17–18 June as a date of seasonal discontinuity. Further evidence of this June singularity is given in Table II which shows the yearly dates (since 1871, the earliest available record) when there were more than 10 wet days (of rainfall > 1 mm) at Kew during the period 1–20 June, and also the number of subsequent wet June days. It can be seen from Table I that June 1964 followed a pattern similar to the other Junes of Table II.

The Junes of Table II were all distinctly wetter than normal, apart from June 1894 which was only a little wetter than average. These wet Junes all ended in a mainly dry spell which extended well into July (except in 1912).

The June 1964 singularity followed a period in which there were particularly marked singularities of the type associated with land-sea differential heating. A recent paper by Baur⁶ draws attention to the exceptionally unbroken series of singularities (anticyclonic and cyclonic) during the previous winter and the unusually large amplitudes of the associated 30-day pressure wave over central Europe, unprecedented for over 200 years. The winter, December 1963 and January and February 1964, was the driest in England for over 200 years.⁷ A striking feature of the winter circulation was its extremely

TABLE I—RAINFALL AT KEW DURING JUNE 1964 FOR 24-HOUR PERIODS BEGINNING 0000 GMT

Date	Rainfall mm	Date	Rainfall mm
31 May	12.3	16 June	0.0
1 June	20.1	17	4.5
2	tr	18	30.1
3	0.1	19	4.2
4	8.6	20	1.2
5	3.3	21	0.0
6	0.6	22	tr
7	7.0	23	tr
8	tr	24	tr
9	0.0	25	0.0
10	0.0	26	0.0
11	0.0	27	0.0
12	11.4	28	tr
13	4.1	29	0.0
14	3.6	30	0.0
15	tr	June total*	98.8

The line after 20 June indicates the termination of the wet spell.

*The mean total rainfall for June (1916-50) at Kew is 43.7 mm.

TABLE II—NUMBER OF DAYS (0000 TO 2400 GMT) WITH RAINFALL MORE THAN 1 MM AT KEW FOR YEARS WITH 11 OR MORE SUCH DAYS DURING 1-20 JUNE, 1871-1964

Year	1894	1902	1912	1924	1926	1935	1946	1964
1-20 June	12	11	12	11	11	14	12	11
21-30 June	0	1	4	0	0	1	4	0

meridional circulation. Further climatological records were broken during March, April and May of 1964. All such singularities and records^{7,8} could help towards or reflect the build-up of a marked European summer monsoon.

The wet period in June was so marked that it might be recognized as a singularity and so alert the forecaster to the possibility of the wet period coming to an end with a change to dry weather after about 20 June. Synoptic charts provided the final clue as to the date of change by showing an extension of the Azores high towards the British Isles on 20 June.

The dates of Table II bear a striking relation to the sunspot cycle, as can be seen from the following dates of sunspot minima given by Waldmeier:⁹ 1901.7, 1913.6, 1923.6, 1933.8, 1944.2, 1954.2, 1964 (approx.) The only sunspot minimum years not associated with dates of Table II are 1879 and 1890 which had the two wettest Junes of the nineteenth century, and 1954 which had an extremely dull, cool and wet summer in England and Wales and an unusual pressure distribution which could be a reflection of a very strong monsoonal effect.^{10,11,12}

Not all the years which showed the marked June 'wet to fair weather' sequence had marked monsoonal conditions, as in 1964. A similar sequence could result from a prevailing zonal flow being displaced by a slight seasonal northward movement of the subtropical high-pressure belt.

Work described elsewhere¹³ suggests an association (1) between the 'monsoonal' type of June singularity and sunspot minima, at least when following large solar amplitudes and (2) between the 'zonal' type of June singularity and the years of increasing sunspots, at least in small-amplitude solar cycles.

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EASTERLY WINDS AND LOW STRATUS AT LEUCHARS

By L. L. ALEXANDER

Summary.—The occurrence of cloud with base below 1000 feet in easterly surface winds at Leuchars is examined statistically over a long period—1950 to 1963. Factors examined include the 900 millibar wind, the lapse rate, the dew-point depression and the difference between dew-point and the sea temperature. Different stratus effects are noted for three types of easterly surface winds. An attempt is made to differentiate between small amounts of low cloud and low cloud of amount $\frac{5}{8}$ or more. Little difference is noted between day and night occurrences or for different wind speeds, though the frequency of stratus at 300 feet and below tends to decrease with increasing wind speed. The main conclusions are listed at the end.

Introduction.—The reputation of Leuchars for weather favourable for flying is marred by the frequency and quick onset of very low stratus with easterly winds. The problem of forecasting the stratus onset is made difficult by the lack of observing stations to the east. Investigations over short periods have been made from time to time without producing any convincing technique for forecasting stratus. It was decided therefore to attempt a long-term statistical investigation in the hope of finding some common factors which would increase the percentage of successful forecasts. The investigation extended over the whole years 1950 to 1959 for certain aspects and, later, 1960 to part of 1964 was included. The material used was that which is readily available to the forecaster at Leuchars, i.e.:

Hourly observations at Leuchars;
 Radiosonde ascents at Leuchars (Shanwell from September 1959);
 Sea temperatures at Bell Rock;
 Average sea temperature charts.

Topography of the area.—Figure 1 is a map showing the sea area to east and south of Leuchars and the high ground in the vicinity. The immediate

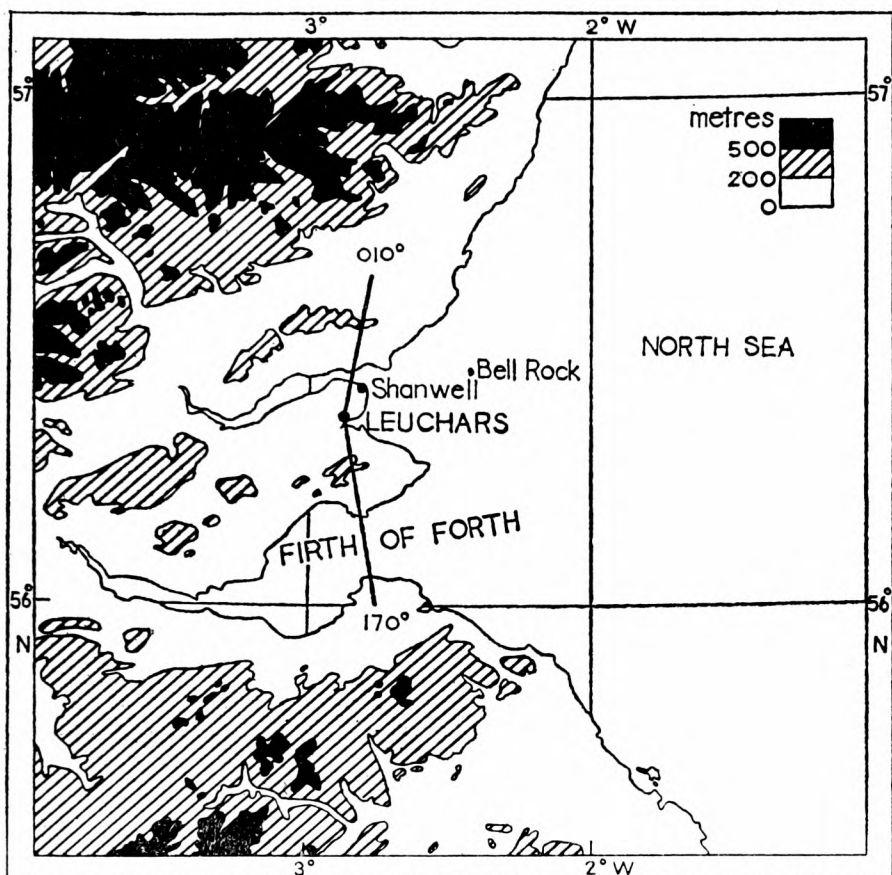


FIGURE 1—MAP OF THE LEUCHARS AREA

southern boundary of the aerodrome is the estuary of the River Eden; at low tide, the estuary is drained almost entirely to mud flats. The effective coastline may be important in those borderline cases where stratus exists over the sea but not over the land. An example of this has been described by Alexander.¹

Statistics of easterly surface winds and incidence of stratus.—

TABLE I—MONTHLY AND ANNUAL PERCENTAGE OF EASTERLY WINDS WITH AND WITHOUT STRATUS, BASED ON HOURLY WIND OBSERVATIONS FOR THE 14-YEAR PERIOD 1950–63

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	<i>percentage</i>												
Without stratus	17	19	27	25	31	25	21	20	18	16	17	14	21
With stratus	3	6	13	8	14	14	13	12	9	8	7	3	9

Note 1.—Monthly or annual number of hourly occurrences are averaged over 1950–63 and expressed as a percentage of the total number of hourly observations in each month or in a year.

Note 2.—‘Easterly’ means with an easterly component, i.e. 010° to 170° .

Note 3.—‘Stratus’ means $\frac{1}{4}$ th or more lower than 1000 feet.

Table I shows that easterly winds and low stratus are most frequent from March to August but Table II shows there is no clearly defined season for maximum frequency of low stratus with easterly winds.

TABLE II—MONTHLY MAXIMUM AND MINIMUM PERCENTAGE FREQUENCIES* OF EASTERLY SURFACE WINDS FOR THE PERIOD 1950-63, AND THE YEAR OF OCCURRENCE

(a) Maximum percentage frequencies												
	Jan. 1963	Feb. 1955	Mar. 1960	Apr. 1956	May 1951	June 1955	July 1962	Aug. 1955	Sept. 1952	Oct. 1952	Nov. 1950	Dec. 1958/59
Without stratus	46	32	60	38	50	37	34	34	31	33	24	28
	1952	1963	1960	1961	1951	1958	1957	1957	1956	1960	1963	1953
With stratus	7	14	26	32	27	35	25	22	26	36	25	19
(b) Minimum percentage frequencies												
	1952	1952	1961	1950	1956	1952	1953	1961	1955	1957	1953	1951
Without stratus	4	5	1	15	12	10	10	8	7	3	8	2
	1953	1952	1961	1950	1961	1962	1954	1953	1955	1950	1956	1951
With stratus	0	0.3	0.5	0.5	1	0.5	2	4	0.1	0.1	0.1	0.1

*Extremes for the 14-year period 1950-63 are expressed as a percentage of the total number of hourly observations in each month.

'Stratus' means $\frac{1}{8}$ or more lower than 1000 feet.

Table II shows the great variability of occurrences of stratus with easterly winds. It also shows that the periods of maximum easterly winds are not necessarily periods of maximum stratus.

Relationship between speed of easterly surface winds and cloud heights.—An attempt was made to relate the height of the cloud base in easterly surface winds to the speed of the wind. No conclusive relationship could be found. Little difference could be found between the day and night occurrences or for different wind speeds. The frequency of cloud at 300 feet or lower tends to decrease with increasing wind speed but occasions have been noted when there has been stratus at 200 feet by day with the surface wind over 21 knots.

Relationship between the 900 millibar wind and the occurrence of stratus with easterly surface winds.—It is known that when the surface wind at Leuchars has an easterly component there may be wide differences between its direction and that of the gradient wind. A random selection was made from the 900 millibar winds found by radiosonde at Leuchars (Shanwell from September 1959), the only proviso in the selection being that the surface wind must have an easterly component. The selection covered various months and years between 1955 and 1964 and was almost equally divided between day and night soundings.

In Table III, it can be seen that the 900 millibar winds examined divide roughly equally between 010 and 040 degrees and 180 and 240 degrees on the one hand and 050 to 170 degrees on the other (136 occasions to 155 occasions).

TABLE III—RELATIONSHIP BETWEEN 900 MB WIND DIRECTION AND THE OCCURRENCE OF STRATUS WITH EASTERLY SURFACE WINDS

900 millibar wind (sector)	Number of occasions with cloud below 1000 feet	Number of occasions examined*
<i>degrees</i>		
010 to 040	5	39
050 to 170	130	155
180 to 240	15	97

*Random selection from occasions of easterly surface winds, 1955-64.

Using this division, it can be seen that 20 of 136 occasions gave stratus with the first grouping and 130 of 155 occasions with the second grouping. It seems to the author that the direction of the 900 mb wind could be a helpful parameter to use in the forecasting of stratus on days with easterly surface winds and suitable temperatures.

Lapse rates and incidence of stratus.—Of the 291 occasions used in Table III, tephigrams were studied for 89 of the Shanwell radiosonde ascents involved. These were all in the months of June and November 1963, and March, April and May 1964. Approximately half the ascents were made at noon and half at midnight.

These ascents were divided into four types:

- (i) Inversion from the surface to 900 millibars.
- (ii) Inversion near the surface then isothermal or with a lapse to 900 mb.
- (iii) Lapse to 900 millibars.
- (iv) Lapse near the surface then inversion to 900 millibars.

TABLE IV—OCCURRENCE OF STRATUS ON CERTAIN OCCASIONS IN 1963 AND 1964 IN RELATION TO TEMPERATURE VARIATIONS UP TO 900 MB

900 mb wind (sector) degrees	Inversion from surface to 900 mb		Inversion near surface then lapse to 900 mb		Lapse to 900 mb		Lapse near the surface then inversion to 900 mb	
	Stratus		Stratus		Stratus		Stratus	
	Absent	Present	Absent	Present	Absent	Present	Absent	Present
010 to 040	0	0	0	1	6	1	0	1
050 to 170	0	1	7	12	19	8	0	12
180 to 240	0	0	2	1	10	5	0	3

'Stratus' means $\frac{1}{8}$ or more lower than 1000 feet.

The number of ascents used (89) in Table IV is not sufficient to form definite conclusions but is sufficient to show that stratus can occur with any type of lapse rate. In particular, it seems from Table IV that stratus formation is associated with the occurrence of an inversion above the layer close to the surface. There is also in Table IV an indication that stability near the surface is not a certain sign of stratus formation and that instability is no bar to stratus formation.

Sea temperatures.—Sea temperatures recorded at Bell Rock were tabulated for April, May, June and July from 1950 to 1958, and for the whole years from 1959 to 1963. No consistent relationship could be found between the frequency of low stratus at Leuchars and above or below average sea temperatures recorded at Bell Rock. The readings were compared with the sea temperature averages prepared by the Fisheries Laboratory, Lowestoft, and issued to Meteorological Offices in 1960. There were few departures from these averages greater than 2 degrees Celsius.

Critical surface temperatures and stratus formation.—The sea temperatures at Bell Rock and the dry-bulb temperature and dew-point depression at Leuchars were combined in an attempt to find a relationship which could be used as a stratus formation indicator.

Table V could be used:

- (a) as an aid in timing the onset of low stratus according to forecast temperatures,

- (b) in forecasting the probability of low stratus and
(c) in forecasting the probable amount of low stratus.

TABLE V—OCCURRENCE* OF STRATUS IN EASTERLY WINDS AT SYNOPTIC HOURS, 1959-63, ANALYSED ACCORDING TO DEW-POINT DEPRESSION AND DIFFERENCE OF DEW-POINT AND SEA TEMPERATURE

Dew-point depression at Leuchars <i>deg C</i>	Dew-point at Leuchars minus sea temperatures at Bell Rock <i>degrees Celsius</i>								Amounts of cloud below 1000 feet
	3 or more	2	1	0	-1	-2	-3	-4 or more	
	<i>percentage</i>								
4 or more	(0)	(0)	4	0	3	0	1	0	1/8-4/8
	(0)	(0)	0	0	0	0	0	0	5/8-8/8
3	(20)	(20)	14	17	8	15	7	1	1/8-4/8
	(0)	(0)	0	3	3	2	0	0	5/8-8/8
2	(29)	(22)	34	24	17	17	17	4	1/8-4/8
	(0)	(33)	28	26	8	13	7	2	5/8-8/8
1	(0)	8	22	26	21	31	17	19	1/8-4/8
	(0)	54	47	51	52	29	13	7	5/8-8/8
0	(0)	(10)	11	9	7	42	18	10	1/8-4/8
	(100)	(80)	78	81	83	32	45	7	5/8-8/8

*Expressed as a percentage of all observations with easterly winds which had the same difference between the dew-point at Leuchars and the sea temperature at Bell Rock and the same dew-point depression at Leuchars; percentages are given in brackets if based on 10 or less observations.

Types of synoptic situations producing easterly winds.—There are three main types of synoptic situations which give easterly surface winds at Leuchars. These are:

- (i) sea breeze,
 - (ii) backing wind ahead of a warm front (transient easterlies) and
 - (iii) long-term easterlies (persistent easterlies).
- Each of these situations was examined.

(i) *Sea breeze.*—It was extremely difficult to decide whether an easterly wind was a 'sea breeze' or not, so sea-breeze occasions were chosen according to two criteria: (1) when anticyclones were centred directly over the area so that any easterly surface wind which occurred was not influenced by any gradient wind, and (2) occasions when the surface wind became easterly after 0600 GMT and dropped to calm or became westerly by about 2200 GMT and when no signs of pre-frontal cloud were evident.

Of 68 sea-breeze occasions thus chosen in the years 1950-59 and during the months April, May, June and July, only 4 produced any stratus. On all 4 occasions there had been radiation fog at Leuchars prior to the onset of the sea breeze and this fog had been taken out to sea by westerly winds. Therefore it can be stated with reasonable confidence that sea breezes as defined above do not produce stratus at Leuchars.

(ii) *Transient easterlies.*—At Leuchars, the surface wind is backed considerably when the gradient wind is southerly. Under these conditions, stratus is a common occurrence. For stratus to form with a very short sea track, the advection of very moist air seems a necessity and this is most likely to occur with an approaching warm front. Normally, any stratus formed by this method would only last a few hours, hence the name 'transient easterlies'.

(iii) *Persistent easterlies*.—The long-period easterly wind is the result of a settled anticyclone over Scandinavia or to the north of Scotland. It is seldom a difficult matter to differentiate between the 'transient' and the 'persistent' types and rarely does the transient develop into the persistent easterly.

Comparison of transient and persistent easterlies.—The time of onset (defined as the time of the hourly observation first showing the phenomenon) of the easterly wind was compared with the time of onset of stratus. The delay in arrival of stratus was greater with persistent easterlies than with transient easterlies as shown in Table VI.

TABLE VI—COMPARISON OF TRANSIENT AND PERSISTENT EASTERLIES IN RELATION TO STRATUS, APRIL–JULY, 1950–59

	Total number of days	Number of days with stratus	Number of days with stratus and rain	Delay of arrival of stratus* in hours	
				With rain	Without rain
Transient easterlies	198	59	52	3.6	9.3
Persistent easterlies	487	232	16	15.2	32.8

*Average delay in arrival of stratus after the onset of the easterlies. The delay ranged from 0 to 14 hours for transient and 1 hour to 2½ days for persistent easterlies.

It can be seen from Table VII that there is a slightly better chance of the stratus at its onset being more broken with transient easterlies than with persistent easterlies.

TABLE VII—HEIGHT AND AMOUNT OF STRATUS AT ITS ONSET,* APRIL–JULY, 1950–59

Height of stratus feet	Transient easterlies Amount of stratus				Persistent easterlies Amount of stratus			
	1/8–2/8	3/8–4/8	5/8–8/8	Totals 1/8–8/8	1/8–2/8	3/8–4/8	5/8–8/8	Totals 1/8–8/8
number of occasions								
0				0			14	14
100	1		1	2				0
200–300	1	1	6	8	1		10	11
400–500	1	8	13	22	2	2	13	17
600–700	3	4	7	14		3	28	31
800–900		4	9	13		5	27	32

*Defined as the time of the hourly observation first showing stratus.

Main conclusions.—

(i) There is no sharply defined season for stratus with easterlies, though easterlies and stratus are most frequent from March to August (Tables I and II).

(ii) The occurrence of easterly winds in any month varies greatly from year to year as does the proportion of easterlies with stratus (Table II).

(iii) The occurrence of stratus with easterly surface winds is more frequent with:

- 900 mb winds between 050 and 170 degrees (Table III),
- an inversion below 900 mb with an unstable surface layer (Table IV),
- a small dew-point depression (Table V),
- a small difference between the sea temperature and the dew-point (Table V).

(iv) Easterlies may be classified as persistent, transient, or sea breeze.

- (a) The persistent easterly type may be prolonged but is usually dry and produces stratus which most often begins as 5/8 to 8/8 after an average time of 15 to 30 hours (Tables VI and VII);
- (b) Transient easterlies ahead of a warm front do not last long, are often accompanied by rain and, after an average time of 3 to 9 hours, produce stratus which quite often begins as 4/8 or less (Table VI and VII);
- (c) Stratus is not formed by a sea breeze but existing stratus over the sea may be brought over land by a sea breeze.
- (v) In borderline cases where stratus exists over the sea but not over the land, the stratus may encroach on the aerodrome more easily at high tide than at low tide because the coastline is nearer the aerodrome at high tide.

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551.509.325

FORECASTING FOG CLEARANCE AT WITTERING

By N. J. ATKINS

In order to forecast the time of fog clearance by Kennington's method¹ it is necessary to have a physical measurement of the height of the fog top, and Barthram's diagrams² can then be used as a convenient way of computing the time of clearance. Many stations are too far away from radiosonde stations for a representative measurement to be available and this paper describes an empirical method of assessing a fog from other known factors so as to get an approximate fog top which can be used on Barthram's diagram. The following factors were taken into account at the time of the forecast:

- (i) surface visibility,
- (ii) whether the sky was visible or not,
- (iii) wind direction and
- (iv) air temperature.

This paper applies to one particular station, Wittering, where an examination of 52 cases of radiation fog between August 1960 and October 1964 led to the five classes listed in Table I. In effect the height of fog top is estimated from the visibility.

TABLE I—FOG CLASSES FOR USE WITH BARTHAM'S DIAGRAMS²

Class	Description	Procedure
A	Visibility greater than 200 yd, sky visible.	Assume depth of fog 10 mb
B	Visibility 200 yd or less, sky visible	Assume depth of fog 15 mb
C	Sky not visible	Assume depth of fog 30 mb
D	Visibility 150 yd or less, sky not visible, surface wind has an easterly component	Determine clearance time assuming depth of 30 mb and add special fog correction from Table II
E	Freezing fog, sky not visible	As class D

Wittering is on sloping ground, low to the east, and the thicker fogs drift from that direction; it is therefore necessary to add a special correction (given in Table II) to the clearance time whenever at the time of the forecast the surface wind has an easterly component and the visibility is 150 yd or less with the sky obscured. The same correction is made for freezing fog when the sky is not visible.

The large correction of 2 hours or more for topographical reasons, shown in Table II, is interesting; there seem to be no intermediate corrections of less than 2 hours. This fact is borne out by Table III which is an analysis of the number of late clearances without the special fog correction applied and the number of early clearances with the special correction applied. Only one occurrence, marked with an asterisk, required an intermediate correction. It is suggested that there is a limiting value to the water content of the radiation fog and that there is a marked increase in water content (probably in the form of larger droplets) as soon as the fog becomes semi-orographic.

TABLE II—SPECIAL FOG CORRECTION

Month	Jan. Dec.	Feb. Nov.	Mar. Oct.	Apr. Sept.	May Aug.	June July
Correction (hours)	+2	+2	+2½	+2½	+2	—

The special fog correction is added when visibility is 150 yd or less, the sky is not visible and the surface wind has an easterly component.

TABLE III—COMPARISON BETWEEN LATE CLEARANCES WITHOUT SPECIAL FOG CORRECTION AND EARLY CLEARANCES WITH SPECIAL FOG CORRECTION

	Without special fog correction applied—late clearing				With special fog correction applied—early clearing			
Hours	¼	½	¾	1	1	¾	½	0
Cases	5	5	3	0	1*	0	2	1

These figures verify that there seems to be no intermediate corrections of less than 2 hours, with the exception of the value marked with an asterisk.

In preliminary investigations there was a marked tendency for forecast times of clearance at Wittering to be too early, perhaps because moisture is evaporated from the vegetation in the partly-wooded agricultural surroundings. This tendency can be reduced if the fog clearance temperature (T_2 in Kennington's notation) is obtained by adding 2 degrees C to the dew-point observed at the time of fog formation. Such a value of T_2 is even higher than would be obtained by assuming a dry-adiabatic lapse rate from surface to a fog top of 600 feet. A comparison between the high value of T_2 and the actual fog clearance temperature is shown in Table IV for the 43 cases of clearing fog investigated. One advantage of this method of obtaining T_2 is that it is possible to make a reasonable forecast of the time of clearance even before the fog has

TABLE IV—COMPARISON OF ACTUAL FOG CLEARANCE TEMPERATURE WITH THE FORECAST VALUE, T_2 , OBTAINED BY ADDING 2 DEGREES CELSIUS TO THE DEW-POINT AT THE TIME OF FOG FORMATION

	T_2 minus actual clearance temperature								
	Positive (T_2 too high) <i>degrees Celsius</i>				Zero (similar)	Negative (T_2 too low) <i>degrees Celsius</i>			
	4	3	2	1		1	2	3	4
Cases	0	1	7	8	23	3	0	0	1

actually occurred—by basing the calculation on the expected minimum temperature and a dew-point 2 degC above the fog-point with an appropriate assumed depth of fog.

In winter there may be no clearance because insufficient insolation is received, or there may be no real clearance because an improvement to mist is quickly followed by fog again.

Figure 1 is a reproduction of part of Barthram's graph showing the time by which insolation available for dispersing the fog will have been received, but an additional dashed line has been added as an aid in forecasting the occasions of no real clearance. There will be no real clearance if the final estimate of the insolation value required to clear a fog falls to the right of the dashed line which has been constructed by studying previous occurrences at Wittering.

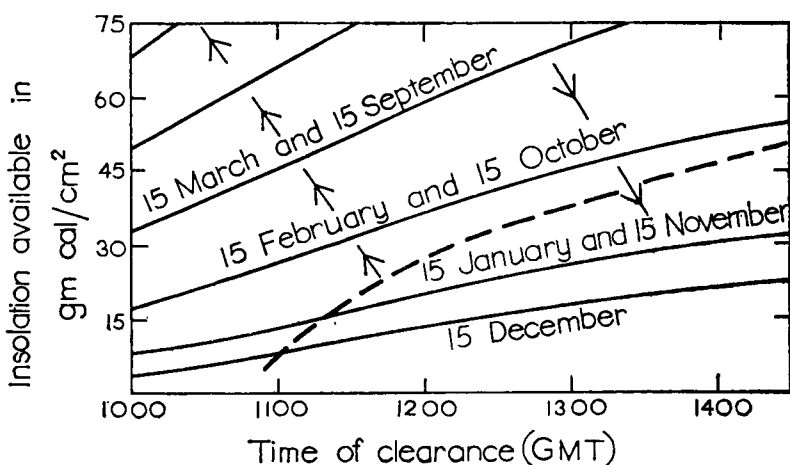


FIGURE 1—BARTHAM'S DIAGRAM, SHOWING INSOLATION AVAILABLE BY VARIOUS TIMES, MODIFIED FOR FORECASTING OCCASIONS OF NO REAL FOG CLEARANCE AT WITTERING

There will be no real clearance if the final estimate of the insolation value required to clear fog falls to the right of the dashed line.

Although the cases were not entirely independent of the method of constructing the line of no clearance, it is interesting to note that of the 10 cases in which no clearance was forecast, 9 were correct and only 1 was incorrect. On the 43 occasions when a clearance occurred, 33 forecasts were correct to within $\frac{1}{2}$ hour and 40 were correct to within 1 hour. These figures should be compared with those found by Heffer³ in his tests of Kennington's method based on a more precise estimate of the height of fog top.

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FORECASTING FOG CLEARANCE AT GAYDON, COTTESMORE AND WATTON

By T. D. D. JENNINGS, C. J. MACEY and B. L. GILES

An empirical method of assessing the height of fog top and the time of fog clearance has been described by Atkins¹ for Wittering, a station with rather special topography. The success which Atkins achieved encouraged the authors to try his method at three other stations each with its own local topography. The results are given in Tables I and II.

TABLE I—ANALYSIS OF FORECASTS OF FOG CLEARANCE AT GAYDON, COTTESMORE AND WATTON

Station	Period months	Total number of fogs	Number of fogs used in the test	Clearance tempera- ture forecast to within		Clearance time forecast to within	
				0.5 degC number of occasions	1.0 degC number of occasions	$\frac{1}{2}$ hour number of occasions	1 hour number of occasions
Gaydon	47	179	50	13	25	21	30
Cottesmore	80	373	48	15	27	10	18
Watton	40	92	54	17	30	19	31

Note: in Atkins' investigation of 52 cases of radiation fog at Wittering, the forecast clearance time was correct to within $\frac{1}{2}$ hour on 33 occasions and to within 1 hour on 40 occasions.

TABLE II—ANALYSIS OF FORECASTS OF PERSISTENT FOG AT GAYDON, COTTESMORE AND WATTON

Station	Forecast of no clearance		Incorrect forecast of clearance number of occasions
	Correct number of occasions	Incorrect number of occasions	
Gaydon	2	1	1
Cottesmore	3	3	4
Watton	3	3	1

Note: in Atkins' investigation at Wittering, 9 out of 10 occasions of no clearance were correctly forecast.

The figures entered under total number of fogs show the number of mornings when water-droplet fog was reported. The next column shows how many of these fogs appear to have cleared by radiation without detectable interference by other processes. At all three stations such fogs are only a fraction of the total. The figures should be compared with those given by Heffer² for Wyton; he found that only 40 out of 122 apparent radiation fogs were uninfluenced by advection in the period between midnight and dawn.

Cottesmore is 460 feet and Wittering is 275 feet above mean sea level. They are only 12 miles apart and both are situated near the top of the slope which rises westwards from the fens to the relatively high ground of the Lincoln Edge and the Northamptonshire Uplands. Although the exposures of these two airfields have many common features, it is evident from Table I that the behaviour of fogs is different at each. Thus Atkins' method, which works so well at Wittering, cannot be used at Cottesmore.

At Gaydon, 430 feet above mean sea level on the crest of a hog's back ridge and a few miles west of the main hills of the Northamptonshire Uplands, the method was more successful. Only with a surface drift from the west is there local up-slope motion at Gaydon and the investigation there was first carried out without applying the delaying factor for easterly drift which Atkins stipulates for Wittering. However, it was found that fogs with drifts having an easterly component are subject to delayed clearance and after a few trials it was

found that the values which Atkins devised for Wittering were also best suited to Gaydon, even though the local topography is different. This special correction has been applied, where appropriate, to the figures for Gaydon given in Table I.

Watton's situation is quite different from that of any of the other stations. It is about 190 feet above mean sea level on the East Anglian Heights and its immediate surroundings are rather flat. Preliminary tests showed that the Atkins' special correction for thicker fogs with easterly winds did not apply to Watton and better results were obtained when 1.5 degrees C instead of 2.0 degC were added to the dew-point to obtain the forecast temperature of clearance, T_2 . Further tests also showed that the correction of +2 hours should be retained for freezing fogs with sky obscured.

Conclusions.—Atkins' method has now been tried at four stations. At three of these stations—Watton, Gaydon and Wittering itself—the method gives useful results. At Cottesmore the method failed and experience at Watton shows that the method should not be applied to any other station without preliminary investigation of both the effectiveness of a delaying factor similar to Atkins' correction for easterly winds and the most suitable addition to the dew-point to obtain the forecast temperature of clearance.

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551.5:061.3:523

THE SIXTH INTERNATIONAL SPACE SCIENCE SYMPOSIUM, MAY 1965

The Committee on Space Research (COSPAR), established by the International Council of Scientific Unions (ICSU), have, over the past six years, held an annual Symposium at the time of the Committee's plenary meetings. The Symposium was to have been held this year from 13 to 19 May, at Buenos Aires but it was decided to hold it instead at Mar del Plata. The efficiency of the Argentinian organizers in transferring 300 participants, together with all the paraphernalia of a major symposium, a distance of 250 miles cannot be too highly praised.

The Symposium comprised sessions on five 'Special Topics' (Galactic and Extragalactic Space Research; Problems of Atmospheric Circulation; Southern Hemisphere Anomalies; Optimisation of Instruments of Space Experiments from the Standpoint of Data Processing; and Life Sciences); sessions on 'Latest Significant Results'; and Open Meetings of the five COSPAR Working Groups (Tracking, Telemetry and Dynamics; the International Years of the Quiet Sun; Data and Publications; the International Reference Atmosphere; Space Biology). A vast number of papers were presented with, in some cases, no time at all allowed for questions and discussion (and since some speakers left as soon as they had delivered their paper there was not always opportunity for discussions outside the formal meetings).

In the sessions on the Atmospheric Circulation two projects involving the use of balloons and satellites were described. In both projects the balloons float at a

constant height and transmit measurements of pressure and temperature. These transmissions will be received by a satellite, for subsequent read-out on command. By repeated 'fixes' on each balloon, from the satellite, wind speeds and direction would also be determined. In the EOLE project, planned by the French National Space Centre, 512 balloons would be released in the southern hemisphere in 1968. The GHOST project, planned by the U.S.A. National Center for Atmospheric Research, envisages many thousands of balloons continuously in the air. A preliminary programme is planned for 1965/6 in which 5000 balloons will be launched in the southern hemisphere, at three levels: 500, 200 and 30 millibars. In this preliminary programme, data transmissions will be received by ships.

In connexion with these constant-level balloon programmes it was pointed out by Dr. Mintz (U.S.A.) that the balloons would tend to accumulate in certain regions, e.g. at 500 mb in the tropical convergence zone, and he suggested that devices be incorporated whereby balloons could be commanded to move to a new level.

Dr. Mintz's comment arose out of a description he gave of his global numerical prediction technique. Using a relatively simple model he found that, starting from an isothermal atmosphere everywhere at rest, a situation quite similar to reality was achieved in about 30 days; and that thereafter the situation showed changes which were, in scale and intensity, very like what occurs in the real atmosphere. He remarked, in passing, that although in his model the Siberian anticyclone was well represented, it disappeared if he removed the Himalayas.

Rasool and Prabhakara (U.S.A.) reported on an analysis of TIROS radiation data and concluded that there is something approaching a radiation balance, over a complete year, for each hemisphere separately. This, in itself, does not appear especially surprising but the authors stated that there is good evidence for a net northward flow of latent heat (water vapour) across the equator and this must, they suggested, be compensated by a southerly flow of sensible heat, by either air or sea currents. (Incidentally, it was announced that the Automatic Picture Transmission System, planned for the Operational Weather Satellites (ros) will include infra-red 'television' as well as cloud photography.)

Dr. Newell, in almost the only reference to the 26-month 'cycle', repeated again his suggestion that this could be accounted for by a 26-month solar cycle which need have an amplitude no greater than 0.1 per cent in radiation intensity.

Several speakers presented, and briefly discussed, results of 'meteorological rocket' firings during the previous 12 months in various parts of the world.

Finally there were papers about eddy diffusivity at high levels. In one a study of the measured concentrations of atomic and molecular oxygen led F. S. Johnson (U.S.A.) to conclude that "the average eddy (vertical) diffusivity between 80 and 105 km cannot be much larger than $10^6 \text{ cm}^2 \text{ sec}^{-1}$. This is ten to a hundred times smaller than values frequently quoted on the basis of vapour trails released from rockets".

R. FRITH

AN ANALYSIS OF TROPICAL STRATOSPHERIC WINDS BY MEANS OF A BAND PASS FILTER TECHNIQUE

By GERALDINE E. EDMOND

In this investigation of the periodicity of tropical stratospheric winds the data selected were the monthly mean zonal wind components for Singapore at 60,000 feet and for Canton Island at 50 millibars (approximately 68,000 feet) as these were the longest records available. The period covered by each set of data was from January 1954 to June 1964, giving in all 126 monthly values.

In order to detect which were the major oscillations in the series of observations, thirteen 25-point filters, designed by Craddock¹ (see Appendix), were applied to each set of data. Each filter is, in fact, a set of weights and is used to calculate for each term of the series a weighted average incorporating a given observation and the 12 observations on either side of it. The resultant series of filtered data is therefore shorter than the original data by 12 terms at either end. In the simplest form of filter used the weights are equal and the resulting series is a 24-month moving average which portrays the long-period trend of the observations. The weights of the other filters are so designed that oscillations within a certain band of periods are preserved, while oscillations outside this band are damped out. If a certain oscillation exists in the original series, application of the correct filter will in theory produce a resultant series with a well-marked amplitude, while if the specified oscillation is absent a correspondingly featureless series will result. A filter with a limited number of terms cannot achieve this aim perfectly, but the set of 13 filters used does provide a considerable degree of separation of the various component oscillations of the series into bands with peak periods at 24, 24/2, 24/3, 24/4, . . . 24/12 months.

The curves for Canton Island and Singapore are shown in Figures 1 and 2, and Table I gives the percentage of the total variance or variability covered by each oscillation. At both Singapore and Canton Island by far the largest amount of the variability can be attributed to oscillation with a period around 24 months. Important contributions come from the 12-month wave, with decreasing contribution from shorter wavelength, everything less than 6 months being effectively 'noise', that is small-scale variations including observational errors.

TABLE I—VARIANCES OF FILTERED SERIES OF ZONAL WINDS FOR SINGAPORE AND CANTON ISLAND

Peak period of oscillation (months)	Effective range of period (months)	Percentage of total variance occurring in each band	
		Singapore	Canton Island
Long Period	> 48	4.3	3.9
24	48-16	58.8	77.3
12	16.0-9.6	12.3	10.0
8	9.6-6.9	8.9	3.1
6	6.9-5.3	6.0	2.5
24/5	5.3-4.4	2.9	1.1
4	4.4-3.7	2.2	0.8
24/7	3.7-3.2	0.9	0.3
3	3.2-2.8	1.5	0.3
8/3	2.8-2.5	0.8	0.2
24/10	2.5-2.3	0.4	0.2
24/11	2.3-2.1	0.7	0.2
2	2.1-2.0	0.7	0.1

Figures 1 and 2 confirm this; the amplitudes of the 24-month waves are much larger than those of the other component waves. There is some indication that

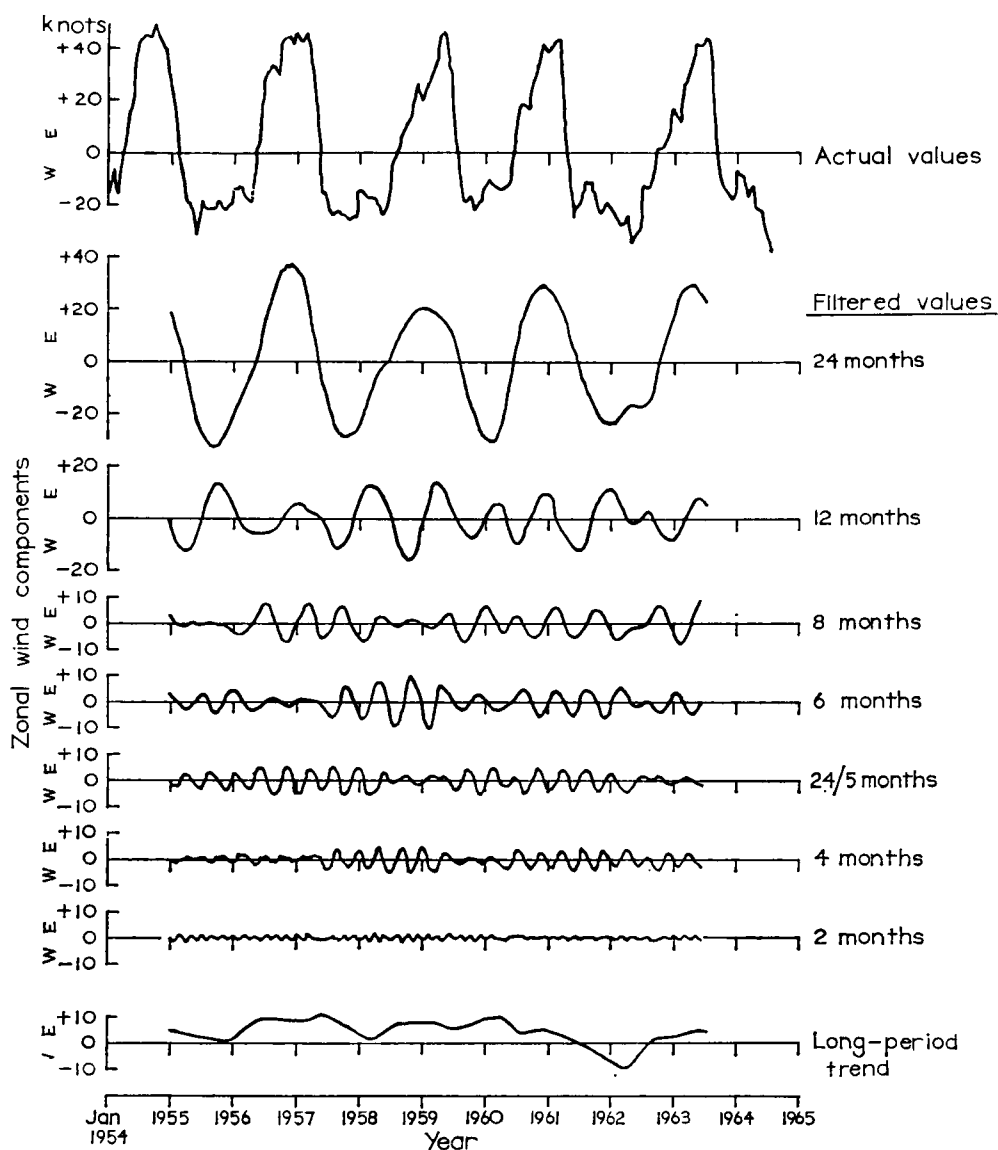


FIGURE 1—ZONAL WIND COMPONENTS AT 50 MB (68,000 FEET) AT CANTON ISLAND
FILTERED TO SHOW OSCILLATIONS WITH VARIOUS PERIODS

Canton Island is $02^{\circ}46'S$, $171^{\circ}43'W$.

the regularity of the oscillations was upset in the spring of 1962 and that some slight change of phase took place. At this time the long-term trend shows a swing to westerly from its general easterly direction. It will be interesting to see how the oscillations settle down during subsequent cycles.

Also apparent from Figure 2 is the notable oscillation in the 6-month wave from 1958–60 which is quite insignificant before and after this period. This is quite a good example of the way spurious cycles so often come and go in meteorological series.

Since the data for Singapore are related to a lower height than the data for Canton Island, the amplitudes of the Singapore waves are on the whole smaller than those for Canton Island. The height discrepancy also explains the lag of the

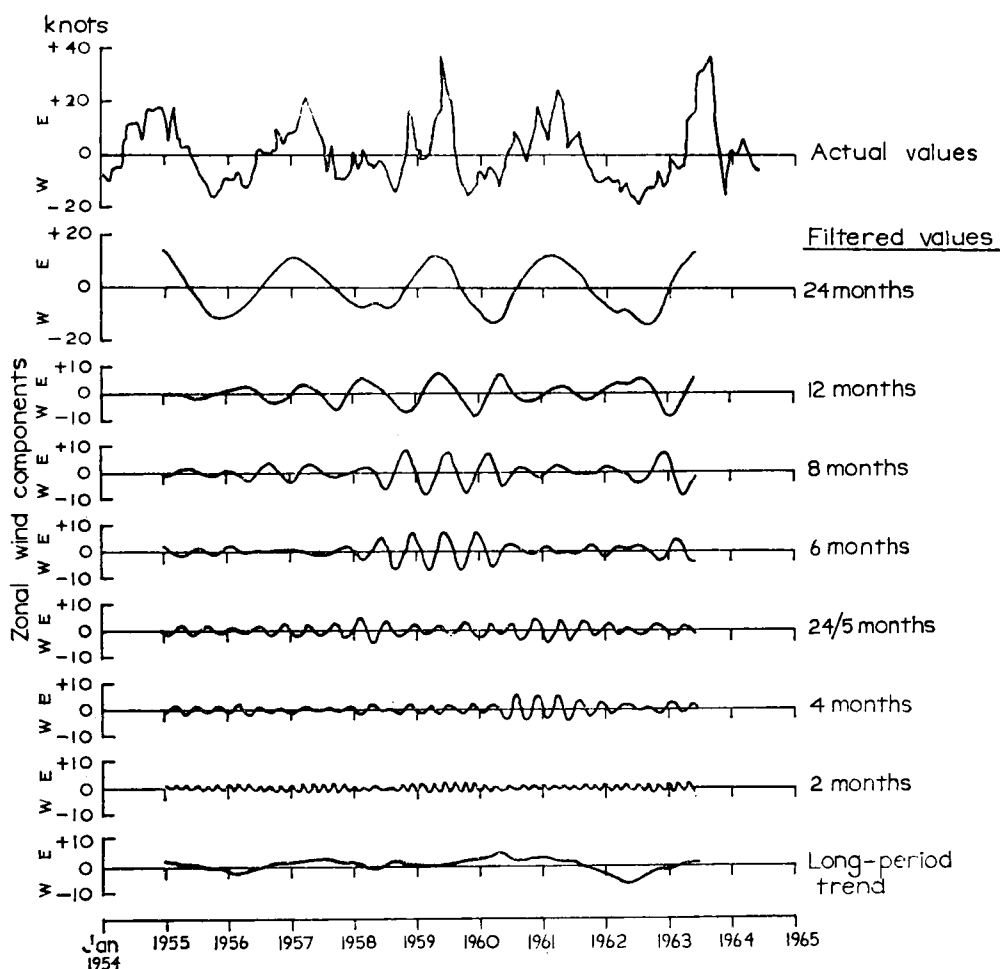


FIGURE 2—ZONAL WIND COMPONENTS AT 60,000 FEET AT SINGAPORE FILTERED TO SHOW OSCILLATIONS WITH VARIOUS PERIODS

Singapore is $01^{\circ}20'N$, $103^{\circ}53'E$.

peaks and troughs of the Singapore oscillation behind those of the Canton Island oscillation, especially for the 24-month wave (this lag was pointed out and investigated by Veryard and Ebdon²).

However, although a lag of about 3 months occurs in the 24-month wave, the lag steadily decreases as the period of oscillation decreases and is only half a month for the 4-month wave, while there is no lag discernible for the 2-month wave. These lags are set out in Table II.

TABLE II—TIME LAG OF FILTERED SERIES OF ZONAL WINDS FOR SINGAPORE BEHIND

THOSE FOR CANTON ISLAND	
Period of oscillation	Time lag
(months)	(Canton Island leads Singapore months)
Long period	3
24	3
12	2
8	$1\frac{1}{2}$
6	1
24/5	$\frac{1}{2}$
4	$\frac{1}{2}$
2	Nil

The set of filters used in this investigation has the property that the sum of the filtered components gives the original wind. It is probably easier to extrapolate the filtered curves rather than the original series and hence to obtain a forecast of the monthly mean zonal winds. In practice, since the contribution of waves with periods less than 8 months is relatively small, only the longer-period oscillations need to be extrapolated, and the sum of the components of these should give a reasonable prediction of the wind. The process of extrapolation is, however, made more difficult by the fact that filtered series necessarily end 12 months prior to the most recent observation, and in order to forecast 2 months ahead the curves must be extrapolated for 14 months.

Westcott,³ Shapiro and Ward,⁴ and others have sought to relate the fluctuation of stratospheric winds to solar radiation and have tried to demonstrate the existence of a 26-month cycle of sunspot numbers. If such a cycle exists it should be revealed by the filtering technique which was therefore applied to the monthly mean sunspot numbers for Zürich for 1749 to 1964. The wave band with peak period at 24 months accounts for only about 2 per cent of the total variance, but it is apparent from Figure 3, which shows plots for three 30-year sections of

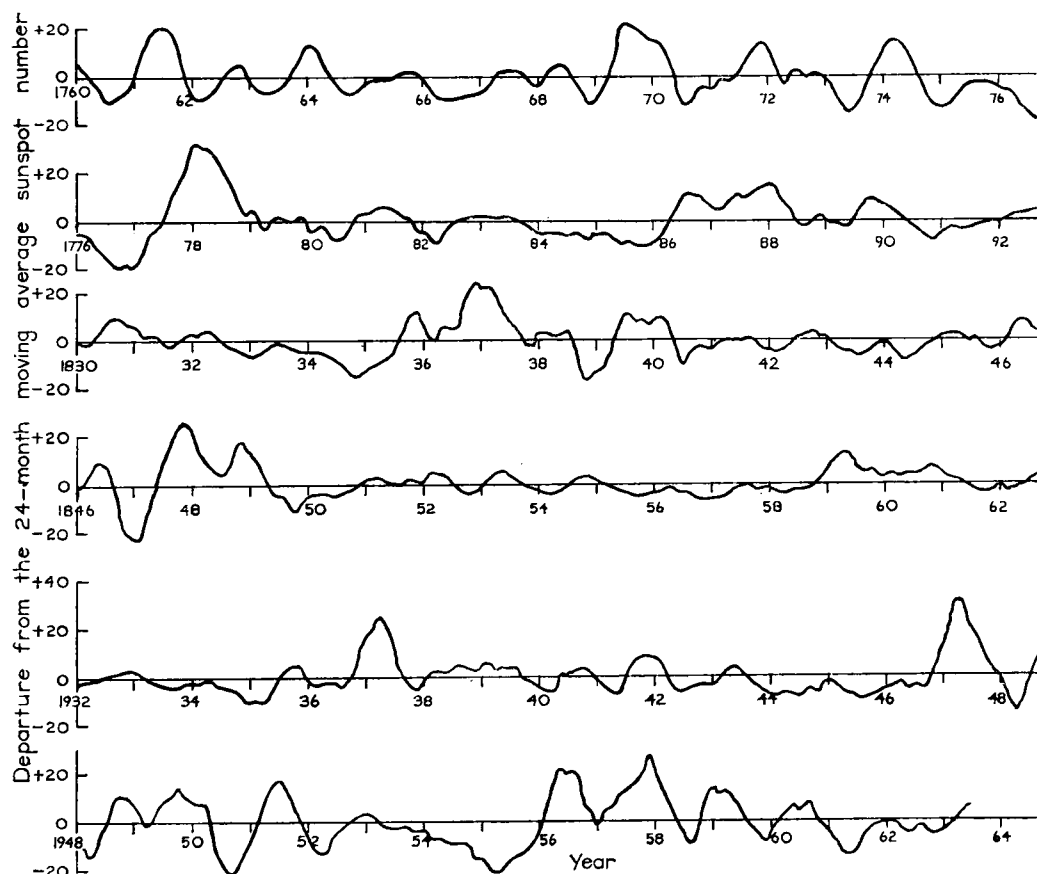


FIGURE 3—ZÜRICH SUNSPOT NUMBERS FILTERED TO SHOW 24-MONTH OSCILLATION AS DEPARTURES FROM THE 24-MONTH MOVING AVERAGE

the results, that there is no outstanding or maintained 24- or 26-month oscillation. We must conclude, therefore, that no regular biennial oscillation of sunspot numbers exists and if there is a connexion between sunspot numbers and tropical stratospheric winds it is by no means a simple one.

Appendix

Calculated filter terms for various bands with given peak periods (the table entries must be multiplied by 10^{-4})

If the terms of a filter are represented by

$$f_1, f_2, f_3 \dots f_i \dots f_{13}$$

where f_i is the i th term of the filter, and successive monthly zonal winds are represented by $V_{t-12}, V_{t-11}, \dots V_t, \dots V_{t+11}, V_{t+12}$, where V_t is the zonal wind at time t , then the filtered value of the zonal wind at time t is given by

$$f_{13}V_t + \sum_{i=1}^{i=12} f_i (V_{t-13+i} + V_{t+13-i})$$

Peak
periods
of oscil-
lation
(months)
long-
period

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}
24	+208	+417	+417	+417	+417	+417	+417	+417	+417	+417	+417	+417	+417
12	-417	-805	-722	-589	-417	-216	000	+216	+417	+589	+722	+805	+833
8	+417	+722	+417	000	-417	-722	-833	-722	-417	000	+417	+722	+833
6	-417	-589	000	+589	+833	+589	000	-589	-833	-589	000	+589	+833
24/5	+417	+417	-417	-833	-417	+417	+833	+417	-417	-833	-417	+417	+833
4	-417	-216	+722	+589	-417	-805	000	+805	+417	-589	-722	+216	+833
24/7	+417	000	-833	000	+833	000	-833	000	+833	000	-833	000	+833
3	-417	+216	+722	-589	-417	+805	000	-805	+417	+589	-722	-216	+833
8/3	+417	-417	-417	+833	-417	-417	+833	-417	-417	+833	-417	-417	+833
24/10	-417	+589	000	-589	+833	-589	000	+589	-833	+589	000	-589	+833
24/11	+417	-722	+417	000	-417	+722	-833	+722	-417	000	+417	-722	+833
2	-417	+805	-722	+589	-417	+216	000	-216	+417	-589	+722	-805	+833
	+208	-417	+417	-417	+417	-417	+417	-417	+417	-417	+417	-417	+417

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THE LENINGRAD RADIATION SYMPOSIUM, 1964

This Symposium, held from 6-12 August, was mainly organized by the Radiation Commission of the International Association of Meteorology and Atmospheric Physics (IAMAP) of the International Union of Geodesy and Geophysics (UGGI) with the World Meteorological Organization (WMO) and the Committee for Space Research of the International Council of Scientific Unions as co-sponsors. There was representation of the three concerned WMO working groups, those on atmospheric radiation (of the Commission of Aerology), on radiation instruments and observations for general use, and on special radiation instruments and observations (of the Commission of Instruments and Methods of Observation), and of the International Society for Biometeorology.

The Radiation Commission, the oldest in IAMAP, holds a Symposium about

every three years, and increasing interest has been shown in the subject in recent times. It is a far cry from the first meeting in Switzerland in 1912, at which only three members and one guest took part, to the 1959 meeting at Oxford¹ with some 76 participants from 19 countries, to the 1961 Vienna meeting with 95 participants from 22 countries and on to the vast increase at the Leningrad Symposium to some 300 participants from 28 countries. This recent surge of interest began with a large increase in radiation stations during the International Geophysical Year (IGY), leading to effective global studies, and has been further stimulated by upper air and satellite observations and the growing possibility of introducing radiation computations into numerical forecasting schemes.

It was most appropriate that the present Symposium took place in Leningrad where Professor Budyko, Director of the Main Geophysical Observatory, prepared his famous radiation atlas,² and where the widely appreciated theoretical and experimental radiation researches of the Institute of Atmospheric Physics at the University—under the direction of Professor Kondratiev—are carried out.

The local arrangements were made by the Soviet Academy of Sciences which supplied a most adequate secretariat and a large assembly hall, in a former palace, for the meetings (this hall was where the original Duma, or Czar's, Parliament was held—there was an interesting glimpse of the building in its original use in the recent television series on the First World War). Most of the abstracts of the papers were available for distribution at the beginning of the Symposium and others were distributed as the Symposium proceeded.

The Selection Committee had the very difficult task of cutting down the large number of papers submitted and of the total of 144 no less than 65 had to be presented by title only. The President of the Commission, for the first time, decided, because of the abundance of papers, not to give the usual President's scientific address. The accepted papers were divided into two classes, those 'invited' being given in the mornings with some half an hour for presentation; the authors of the afternoon 'contributed' papers were allotted only 10–15 minutes. The two main languages were English and Russian and excellent simultaneous translation facilities were provided. Owing to the large number of papers the official discussions were inevitably too hurried but there was ample opportunity, which was taken by all concerned, for discussions outside the set periods, although the working days were long. (Sunday, the only free day, was agreeably occupied by a river excursion to a historic palace; there was a splendid evening reception, a most pleasant concert and, immediately the Symposium finished, organized tours in and around the city, including visits to scientific institutions.)

There were six separate sections, a day being devoted to each section, the pattern being that some 4–5 invited papers were given in the morning and some 5–10 contributed papers in the afternoon. There were only two cases of overlap of sections which are mentioned below. Each section had a convener who opened the discussion, either with a short review or a relevant paper. No detailed publication of the papers is to be attempted by the Symposium organizers, as many will no doubt find their way into the literature, but it is intended that the programme, titles and abstracts of the papers be published in a special UGGI Monograph. Some notes follow on the problems discussed in the various sections.

Theory of radiative transfer in planetary atmospheres.—Professor Sekera (University of California) spoke on the recent developments in attaining a realistic model of a planetary atmosphere, namely the solutions in which multiple scattering and the state of polarization of diffuse radiation are taken fully into consideration. The work is an extension of Chandrasekhar's³ analysis and provides a rigorous and computationally feasible method of solution of such general problems as the effect of ozone absorption on scattering in the near ultra-violet, the broadening of absorption lines due to scattering, the effect of scattering on atmospheric emission, radiative transfer in a real atmosphere in the near infra-red (dust particle scattering being taken into account) and radiative transfer in a turbid atmosphere or in a cloud layer. G. V. Rosenberg (Institute of Physics of the Atmosphere, Moscow), followed by outlining the Russian work on this difficult problem; approximate solutions of the transfer equations had been obtained with certain models and the influence of different types of clouds had been considered. Further speakers from the U.S.S.R. and U.S.A. outlined other methods used in similar computations. At the end of the session there was a series of papers on measurements and computations in turbid atmospheres; the absorption, in addition to the scattering, of radiation by atmospheric aerosols was emphasized, notably by Sekihara (Meteorological Research Institute, Tokyo).

Infra-red spectroscopy of the atmosphere.—Like the first section, this section was mainly concerned with theoretical studies but there was also some comparison with the experimental data in which the discrepancies showed there was still much to learn in the subject. W. S. Benedict (Johns Hopkins University, Baltimore) opened with a review of the current position regarding several problems basic to the theoretical interpretation of the detailed structure of molecular bands in the atmosphere. He also described the work on the study of the solar spectrum using a spectrograph, of the University of Liège, installed at the International Scientific Station of the Jungfrauoch (Switzerland), elevation 3580 metres. Subsequent speakers (from U.S.A., U.S.S.R., U.K., Germany, Canada and France) discussed various aspects of the subject and it was notable that here, as well as in a paper given in Section 1, the atmospheres of the planets Venus and Mars were being considered in some detail.

Radiation climatology.—Professor Budyko opened with a paper on the study of the solar radiation régime on the surface of the earth. He mentioned the useful increase in radiation stations in recent years and the work done leading to the preparation of his atlas and of more detailed maps available at the Main Geophysical Observatory, but stressed the fact that the world network is still very uneven in that the oceans and vast land areas are not covered. Radiation climatological data were used for solving different applied problems, such as evaporation from a land surface, the rate of photosynthesis of vegetation and the thermal state of man in the open air—leading to deduction of correct clothing requirements. There were detailed radiation climatology studies from Sweden (Ångström, 'Atmospheric turbidity as a parameter within radiation climatology'); from the U.S.A. (Bennett, 'A contribution to the insolation climatology of the United States'); from the U.S.S.R. (Pivarova, 'Radiation climate of the U.S.S.R.'; Rusin and Marschunova, 'The radiation balance of Arctic and Antarctic'; Barteneva and Poliakova, 'Study of extinction and scattering of light in hazes, fogs and precipitation'; from Germany (Barg, 'The space and

time distribution of radiation and radiation balance at sea level'); and from Japan (Yamamoto and Tanaka, 'Aerosol climatology as estimated from direct solar radiation measurements').

A simultaneous afternoon session of this section, which the writer was unable to attend, was concerned with radiation observations from satellites and seven papers were presented on this subject, mainly on the evaluation of the radiation measurements made by means of the TIROS satellites.

Radiation problems as related to atmospheric dynamics and the general circulation.—Professor Goody (Harvard University) introduced the subject by stating that up to quite recently people were deterred, by its complexity, from attempting to solve the problem of relating radiative transfer to the atmospheric circulation. It was thus decided that the Commission for Radiation and the Commission for Dynamical Meteorology of IAMAP should combine to discuss the problem here. Rakipova and Shneerov (Main Geophysical Observatory, Leningrad) discussed past attempts and a present attempt to take radiation heat transfer into account in problems of the theory of climate and numerical prediction. Such factors as the selective absorption of long-wave and short-wave radiation, the latitudinal distribution of the albedo of the earth-atmosphere system and the amount of radiation absorber (water vapour and carbon dioxide) were taken into consideration. This approach to the problem allows not only a closer approximation to the actual distribution of temperature but also to correct values of radiation heat fluxes. Several authors were quoted as using balance ratios to allow the more precise calculation of radiation heat transfer taking cloudiness into account: experimental calculations (with a computer) show that this factor makes short-period forecasting more successful. The other papers presented in the morning session, 'A numerical integration of the general circulation of the atmosphere with the explicit calculation of radiative transfer', 'Some aspects of the role of heat sources in atmospheric dynamics' and 'The diurnal wave in a grey stratified atmosphere: a radiative-convective model' considered the main subject in some detail, but these papers and the discussion on them indicated that there was much work still to be done before a synoptic tool was fully developed. In the afternoon session the papers had particular reference to the relation between radiative transfer and convection.

There was a simultaneous afternoon session on another day which the writer was unable to attend; four papers were presented with the titles, 'Radiative heating and motions in the mesosphere', 'The influence of photochemistry and radiative transfer on stratospheric dynamics', 'Radiative heat exchange as a dissipative factor in the atmosphere' and 'The decay of small temperature perturbations by thermal radiation in the atmosphere'.

Surface and network instrumentation.—The co-conveners for this section, A. J. Drummond (U.S.A.) and Dr. W. D. Yanishevsky (U.S.S.R.), opened the session by giving separate papers, Drummond on 'A review of new techniques and associated instrumentation for the measurement of component and net flux solar and terrestrial radiation' and Yanishevsky on 'The principles of radiation instruments for network use in the U.S.S.R.'. Drummond, in a general opening statement, mentioned the great improvement in instruments which has been helped by the demand for accurate instruments for space measurements. There is more emphasis now on the international comparison of instruments. Balance meters were first compared at Hamburg eight years ago and another international comparison, on a much wider scale, is now beginning. Solarimeters last

compared internationally at Davos in 1959 were being compared again there after this Symposium. His paper reviewed a number of new scientific approaches which have been introduced, with the relevant instrumentation, by the Eppley research team in the post-IGY period, notably in regard to the improvement of thermopile radiometers particularly for high-speed response and for more accurate illumination measurements, to the provision of precision filters to isolate specific spectral bandwidths, and to the more accurate determination of long-wave exchange. Yanishevsky gave a full and most interesting account of the development of Russian radiation instruments in the past, with which he himself had been concerned for many years, and of the plans for the future. L. Jacobs (U.K.) in describing 'The operation of a network of shipborne radiation instruments' summarized the results from some of the solar radiation measurements from the British Ocean Weather Ships in the North Atlantic, which were in reasonable agreement with the estimates made in the Russian *Atlas of heat balance*. He explained the improvement of instrumentation and mountings since the IGY period and described how the scheme was being extended to British ships engaged on voyages all over the world; six ships had already been equipped with pen recorders, and a total of some 20 ships was planned with magnetic tape recording for easy analysis of the results. The Meteorological Office data logging equipment, now in use at most British radiation recording stations, and to be installed in the four Ocean Weather Ships, was briefly mentioned. Other maritime nations were urged to start similar schemes for the making of routine radiation recordings at sea to obtain essential climatological information.

Professor Kondratiev followed by describing a complex of spectral apparatus for the experimental investigation of the short-wave radiation field in the earth's atmosphere which is to measure the spectral fluxes of global, scattered and direct radiation, the angular distribution of spectral sky brightness and the spectral albedo of the surface. Preliminary measurements have been made at ground level and aircraft observations are planned; the experimental results are to be compared with the theoretical calculations.

In the afternoon session papers were given on the network instrumentation and techniques in India (Mani) on the calibration and comparison of instruments (both in the U.S.S.R. and the U.S.A.), on a multichannel measuring and integrating equipment (Paulsen, Norway), on the measurement of sky and surface radiances by quantitative photography (Kovsky, U.S.A.) and on scattered sky radiation, its measurement, correction and application (N. Robinson, Israel).

Experimental investigations of the radiation field in the free atmosphere.—In this section, the measurements obtained by instruments borne aloft by radiosonde, aircraft and sounding rockets were described. Professor Kondratiev opened the discussion with a paper on 'Balloon investigation of radiation fluxes in the free atmosphere' and was followed by Bargman (U.S.A.) describing the infra-red and visible radiation measurements by radiometer, spectrophotometer and interferometer on high-altitude balloon flights at 35-km altitude. These and later speakers emphasized that the instrumental observations obtained by ascents from below are to be supplemented by observations from instruments on satellites. Two of the papers gave the principles of projected methods of the determination of cloud-top altitudes by radiation measurements from a satellite. The wide range of subjects discussed is illustrated by the titles of some further

papers, 'Measurements of ozone production by solar ultra-violet radiation', 'Measurements of infra-red radiative flux in the upper air over Poona', 'Chemical instability of the stratosphere' and 'Optical probing (by searchlight) in the U.S.A., instrumentation and results'.

L. JACOBS

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REVIEWS

Probleme der Gewitterforschung, 1. *Das Gewitter in heutiger Sicht* by Dr. Hans Israël. 6½ in × 6¼ in, pp. 60, illus., Westdeutscher Verlag, 567 Opladen/Rhld, Ophovener Strasse 1–3, 1964. Price: DM 29.50.

This 60-page monograph is the first of a series on the problems of thunderstorm research. Written in German, it is a general review of the present state of knowledge. At first sight it appears to be commendably up to date: of the 134 references cited the latest is to be published in 1965 (the earliest paper quoted was written by Faraday in 1845).

This is not a book for the general reader; it omits almost all the fascinating background of the eighteenth century work. After an introductory paragraph, which whets the appetite with a tit-bit about d'Alibard's proof of the identity of lightning and an electric spark in 1752, there is nothing. Benjamin Franklin who proposed the experiment d'Alibard carried out and who made his famous kite experiment in the same year is not mentioned.

Neither is this a book for the research worker, nor the meteorological physicist. As an account of the dynamics, energy transformations and electrical processes of storms it is almost entirely descriptive. Only rarely are numerical values given.

The section on dynamics consists mostly of a summary of the results of the post-war American 'Thunderstorm Project' with no mention of later work on severe storms in Britain and the United States.

In the section on energy transformation the author concludes that in a typical storm the rate of transformation into electrical energy depends on, and is an order of magnitude less than the 60,000 megawatts obtained from, the release of latent heat.

The annual number of days with thunderstorms is shown on a chart based on reports for the year 1953 and 1956. The northern and southern limits of storms are roughly at the edge of the pack-ice. The isopleth with the highest value is for 180 days/year, around Lake Victoria. Java is shown with only 100 days/year. This is so much less than the average 322 days/year which occurred in Buitenzorg (now Bogor) in the years 1916–19 and which gives the island its place in the record books, that we might have expected some comment from the author but there is no mention even of this record value.

The section on electrification processes is the most comprehensive one. Processes which occur in clouds and which laboratory work has shown to generate charge are diligently attributed to their investigators. The author concludes that no process is likely to be the only significant one and that the

main problem now is to determine the relative importance of the various processes, but he does not assess each of them quantitatively. Reports of tropical thunderstorms generated in clouds containing ice are not discussed.

Many of the deficiencies of this book may arise because it has been judged alone. As an introduction, when the whole series is available, it may have some value. By itself it covers roughly the ground that is covered on thunderstorms on an initial course of lectures for forecasters. More comprehensive and more interesting texts at the same level are already available in English.

S. G. CORNFORD

Gaseous composition of the atmosphere and its analysis, by B. A. Mirtov (translated from the Russian). 9 $\frac{3}{4}$ in \times 6 $\frac{3}{4}$ in, pp. 209, *illus.*, Israel Program for Scientific Translations (distributed by Oldbourne Press, 1-5, Portpool Lane, London, E.C.1), 1964. Price: 90s.

This book is primarily concerned with instrumental technique, as used both in the USSR and elsewhere. Some results are given and these are summed up in a six-page 'Conclusions'. An even shorter summary is possible:

Up to 100 km the atmosphere is thoroughly mixed.

Above 100 km dissociation and gravitational separation become important but "final conclusions . . . must await new experimental data".

In addition some sketchy data are given about the occurrence of ionization.

There is no discussion of water vapour at all. Ozone is discussed in an Appendix, written by G. S. Ivanov-Kholodnyi. This is a 19-page section followed by 169 references; but the discussion is superficial and, in places, misleading (e.g. the statement that "One must regard the small fluctuations in the overall ozone content, which are sometimes observed from day to day, with a certain suspicion"; and "The discussions as to the justification for using the inversion (Umkehr) effect can thus be regarded as closed, and the method may be assumed to be both reliable and useful").

The translation appears to be good. There is no index.

R. FRITH

Allgemeine Klimageographie, by J. Blüthgen. 10 $\frac{1}{4}$ in \times 7 in, pp. xiv+408, *illus.*, Walter de Gruyter & Co., Genthiner Strasse 13, Berlin 30, 1964. Price: 48 DM.

In his treatment of climate, Aristotle used the term 'meteorology' (study of things on high) but there has been a tendency to reserve 'meteorology' as a term to denote the study of weather processes. There has also been a tendency to regard climatology as the collection and classification of climatic data, although attempts by Poseidonios to relate climate to the sun's inclination are evidence of an informed use of the word 'klima' and of an early study of process. The re-introduction of the study of process within climatology has led to the development of the term dynamical climatology, a term clear in meaning but nevertheless not without suspicion of tautology.

A similar obscurity is attached to the relations between climatology and geography. The original use of yearly isotherms in the designation of climatic areas was due to Alexander von Humboldt, one of the founders of modern geography. The collection and plotting of climatic data became part of the content of geography. The author of 'Allgemeine Klimageographie' suggests that in fact climatology became part of geography and remained so despite the

growth of synoptic meteorology. Now, however, with the growth of knowledge of the upper atmosphere, climatology must be regarded as an independent discipline, and only part of climatology is of immediate significance to geographers. For this part he proposes the term 'Klimageographie'. Blüthgen does not suggest that this absolves the geographer from a study of processes, indeed he advocates a genetic approach, but that the strongest emphasis should be placed on the phenomena most immediately affecting the earth's surface. Although the adequacy of this approach may be questioned, the content of this book, which forms part of a series with the aim of providing an adequate background in systematic geography at university level, is in accord with this definition. University geographers in this country will nevertheless find the treatment of such themes as stability and atmospheric circulation over-simplified and not sufficiently mathematical. For geographers specializing in climatology or exploring the former bounds between the two disciplines the treatment is correspondingly more inadequate, although giving a readable account of much modern research.

The work is divided into nine main sections, of which the first is an account of the historical development of climatology. The second section, occupying half the book, is a description of climatic elements, subdivided conventionally into temperature, water vapour, pressure and winds. The presentation is clear and well illustrated and the material up to date, but it is revealing of the approach that the section on rainfall deals only briefly with the problems of coalescence, and the section on 'fall' winds makes only brief mention of lapse rates. The third section deals with synoptic 'Klimageographie' and English readers will find the continental emphasis stimulating. The general circulation of the atmosphere is dealt with in section four. Here too, the approach is generally non-mathematical but the description takes account of recent work on the circulation of the atmosphere by Rossby, Reihl, Sutcliffe and Flohn. Climatic types are dealt with in section five; climatic change forms the subject matter of section six and climatic classification of section seven. The treatment, drawing upon German research, will appear fresh to many English readers and these sections are to be considered the most stimulating parts of the book.

Sections eight and nine deal briefly with attempts at climatic control and the mitigation of climatic effects by man, and with acclimatization. A good bibliography is given for each section. The works consulted are mainly of German language, but there are also French, American and British references.

E. M. YATES

551.593.63

NOTES AND NEWS

Halo display at Bracknell, Berkshire, on 11 May 1965

I first noticed bright mock suns with tails (part of the mock-sun ring) to the left and right of the sun (about 22° away) at 1745 GMT; the one to the left was particularly brilliantly coloured. These persisted and at times the entire upper half of the 22° halo was also visible, showing red near the sun and orange to yellow outside. At 1840 GMT two brilliant arcs appeared (arcs CD and CE in Figure 1); they were flexed with their concave side towards the sun like the horns of a ram (see Plate II). It is noted in the *Observer's Handbook** that

*London, Meteorological Office. *Observer's Handbook*. 2nd edn. London, HMSO, 1956, p. 130.

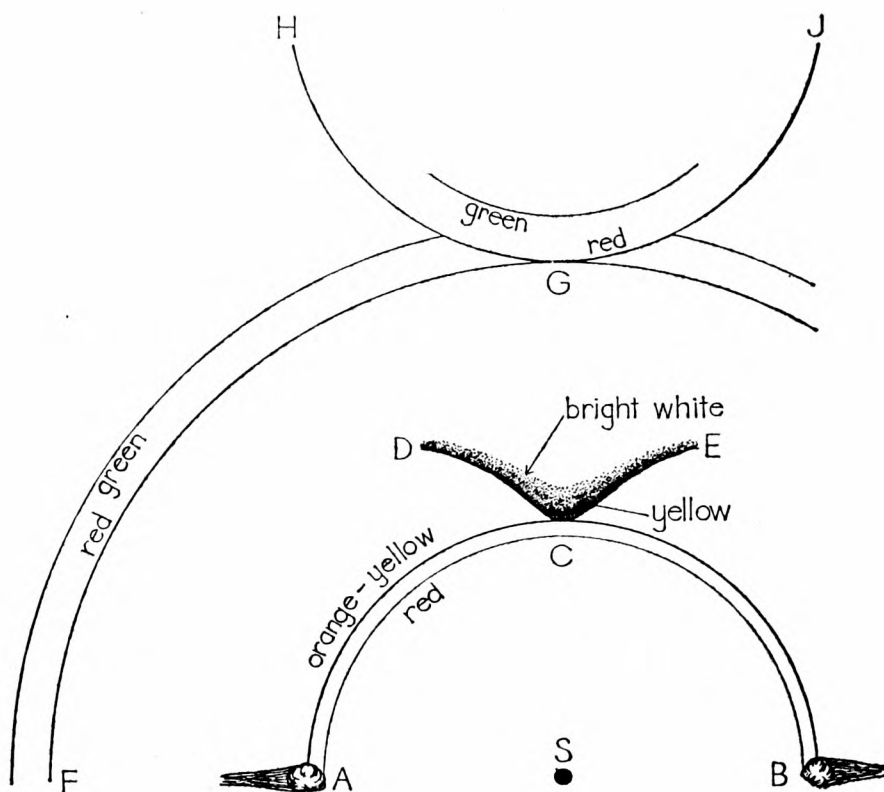


FIGURE 1—DIAGRAMMATIC SKETCH OF THE SOLAR HALO PHENOMENA SEEN AT BRACKNELL ON 11 MAY 1965

A, B Mock suns
CD, CE, Arcs of contact
ACB 22° halo
FG 46° halo

S Sun
HGJ Circumzenithal arc

when the sun is low the arcs of upper contact appear with their convex sides turned towards the sun. By 1850 a portion of the 46° halo (FG in Figure 1) became visible showing a pure red on the sun side and a broad green belt on the outside; a few minutes later a portion of the circumzenithal arc appeared, in contact with the 46° halo and similarly coloured. By 1910 GMT all had faded except one brilliantly coloured mock sun (B in Figure 1) but at 1935 the bright arcs of contact (CD and CE) again appeared for a few minutes.

R. K. PILSBURY

AWARD

We note with pleasure that the International Meteorological Organization Prize for outstanding work in meteorology and international collaboration, has been awarded for 1965 to Professor S. Petterssen from the United States of America by the Executive Committee of the World Meteorological Organization during its 17th session.



Photograph by B. D. Mason

PLATE II—SOLAR HALO PHENOMENA SEEN AT BRACKNELL ON 11 MAY 1965

The arcs of upper contact are shown as CD and CE on Figure 1 on page 315.



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PLATE III—WEATHER RADAR AERIAL ON THE ROOF OF THE METEOROLOGICAL
OFFICE HEADQUARTERS AT BRACKNELL

OFFICIAL PUBLICATION

SCIENTIFIC PAPER

No. 21—*Estimation of rainfall using radar—a critical review*, by T. W. Harrold, B.Sc., D.I.C.

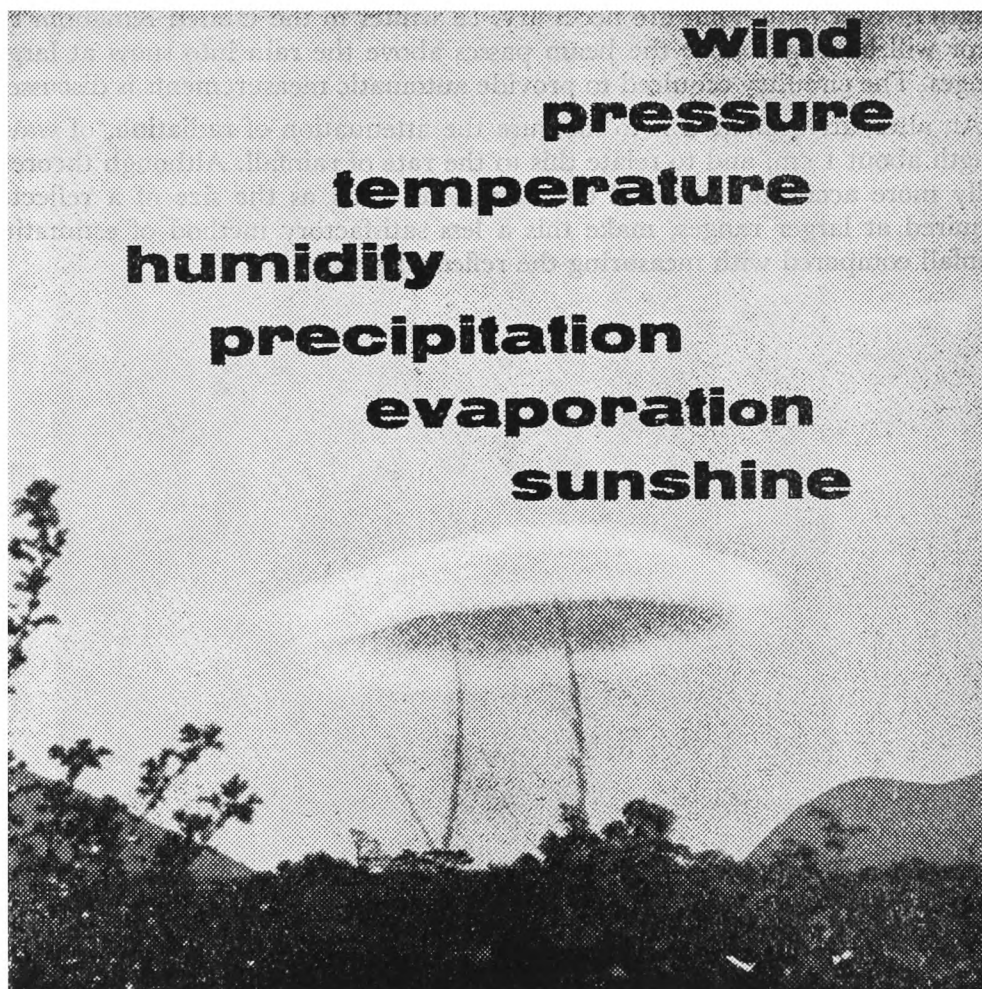
This publication contains a critical review of the possibilities of using a weather radar to measure rainfall over an area, such as a river catchment, as it falls. Two methods are discussed.

By relating the power reflected from the rain to the rate of rainfall it is possible to estimate the rainfall amount, the probable error in such an estimate being 25 per cent. To achieve this accuracy a narrow beam width and a wavelength greater than 5 cm are necessary. In winter in the United Kingdom the error will be larger since the beam passes above the rain into snow at larger ranges. The circuitry required to provide automatic measurements is discussed.

An alternative method is to measure the attenuation of radiation, of wavelength about 1 cm, and to relate this to the rate of rainfall. Although theoretically more accurate, practical considerations, such as the size of a reflector required at larger ranges, make this a less satisfactory method of estimating rainfall compared with measuring the reflected power.

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THE ESTIMATION AND VARIABILITY OF PRECIPITABLE WATER

By G. R. R. BENWELL

Introduction.—In order to improve the forecasting of cloud and to provide satisfactory quantitative forecasts of rain it is probable that the three-dimensional field of water vapour in the atmosphere will need to be defined in more detail than is possible at present from the current aerological network, especially over the Atlantic. To overcome the lack of upper air data recourse might be made to the use of estimates of water vapour based on the synoptic observations available on surface charts and further estimates based on the data available from the upper air network for previous observational hours might also be incorporated.

These possibilities were explored using precipitable water in the layer between 1000 mb and 500 mb as the parameter representing the water vapour of the lower atmosphere. Precipitable water of a column of air is defined¹ as “the depth of water (alternatively expressed as the total mass of the water) that would be obtained if all the water vapour in the column of unit area cross-section were condensed on to a horizontal plane of unit area. ‘Precipitable water’ is a useful measure of the water vapour content of an air column. The term is not, however, to be regarded as implying that the amount of water may, in fact, be precipitated by an actual physical process”. For practical purposes the precipitable water contained in the lower troposphere can be regarded as sufficiently representative of the water vapour available for the rain processes. The layer from 1000 mb to 500 mb was chosen in preference to the layer from the surface to 500 mb, although the latter is more strictly a measure of the available moisture, as it seemed reasonable to examine the behaviour of water vapour contained between two constant-pressure surfaces rather than that contained in a layer which is of more variable depth and which is, furthermore, correlated with surface pressure.

Practical computation of precipitable water.—In the c.g.s. system of units the expressions for precipitable water¹ in centimetres and grams are numerically equal and are given by the approximate expression

$$\text{precipitable water (cm or g)} = \frac{1}{g} \int_{p_2}^{p_1} r dp ,$$

where p_1 and p_2 are the pressure in millibars at the bottom and top of the column respectively, r is the mixing ratio (g/kg) and g is the acceleration of gravity.

The precipitable water in a column 100 mb deep which has a mean mixing ratio r_m is therefore approximately equal to $r_m 100/980$ cm or $r_m(1.02)$ millimetres: in practical calculations this can be taken as r_m mm, a straightforward conversion.

To compute the precipitable water between 1000 mb and 500 mb from a radiosonde ascent it is convenient to consider the layer as composed of five 100-millibar layers. A mean mixing ratio is determined for each layer by drawing the mixing ratio line which results in the areas bounded by the dew-point curve, the isobars defining the layer and the mixing ratio line itself, being equally distributed on either side of this line. Figure 1 gives an example of the construction of mean mixing ratio lines for two layers (900 to 800 mb and 600 to 500 mb) on a typical sounding. The values of mean mixing ratio for the five layers, when added together, can therefore be taken as representing the precipitable water in mm for the layer 1000–500 mb. It can be argued that some adjustment should be made to the precipitable water determined as above since the variation of humidity mixing ratio as represented on the tephigram is not a linear one (see Figure 1): in practice, however, such a refinement is generally not justified since there are appreciable errors in the observing and recording of humidity and water vapour in the atmosphere.

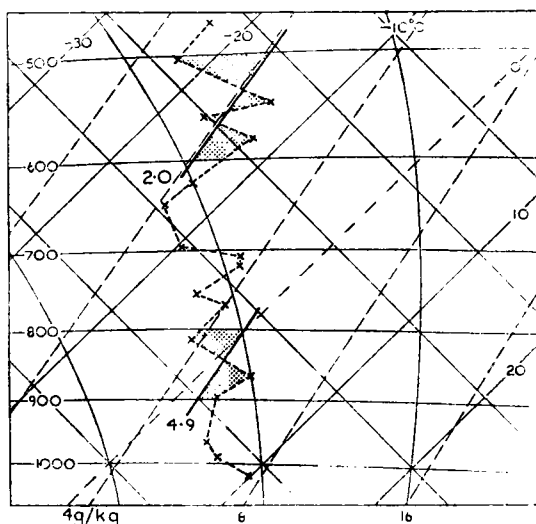


FIGURE 1—EXAMPLE SHOWING COMPUTATION OF PRECIPITABLE WATER IN THE LAYERS 900–800 MB AND 600–500 MB

x - - - x Dew-point curve

2.0 and 4.9 are the mean mixing ratios for these two layers in g/kg.

The spatial and temporal variations of precipitable water.—In devising an analysis technique for humidity it is essential to know how much the precipitable water parameter can vary in space and time. Not a great deal of work has been done on these lines, but Penn and Kunkel² obtained interesting statistics from an examination of mixing ratios at 1000 mb, 850 mb and 700 mb using a unique series of 168 hourly radiosonde ascents made in Massachusetts in April 1960. Autocorrelation coefficients were determined between mixing ratios over periods up to 24 hours and it was found that the correlation at the three surfaces remained above 0.80 for periods up to 4 hours, fell to between 0.65 (850 mb) and 0.40 (700 mb) over the 12-hour period

and to almost negligible values over the 24-hour period. Figure 2 shows the correlation for the 700 mb mixing ratio for periods from 1 hour to 24 hours (taken from Penn and Kunkel's paper). For comparison Table I shows the correlation between values of the 1000–500 mb precipitable water parameter over periods of 12, 24 and 36 hours from the initial times 0000 GMT and 1200 GMT, using data from the three ocean weather stations 'I', 'J' and 'K' for the five months June to October, 1963: as expected the initial time from which the periods are measured had little effect.

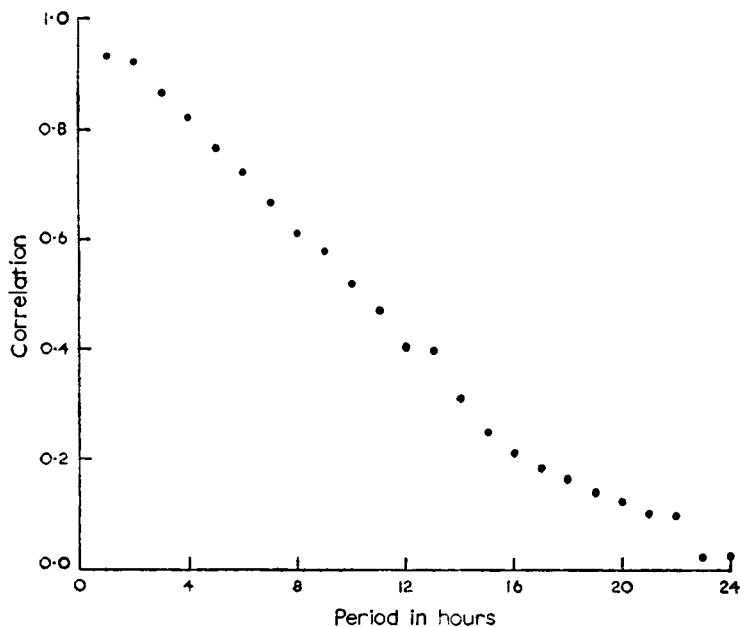


FIGURE 2—AUTOCORRELATION OF MIXING RATIO AT 700 MB OVER PERIODS FROM 1 TO 24 HOURS

After Penn and Kunkel²

TABLE 1—AUTOCORRELATION OF 1000–500 MB PRECIPITABLE WATER FOR PERIODS OF 12, 24 AND 36 HOURS AT OCEAN WEATHER STATIONS 'I', 'J' AND 'K' IN JUNE TO OCTOBER 1963.

	Autocorrelation coefficient	
	Period starting 0000 GMT	Period starting 1200 GMT
12-hour period	0.47	0.47
24-hour period	0.26	0.23
36-hour period	0.23	0.15

It is clear therefore that the observed value of precipitable water at a place is not normally a good estimate of the value at that place 12 hours later.

To obtain rough quantitative estimates of the order of the spatial and temporal variations which could occur, the data for the radiosonde stations in the British Isles and neighbouring countries during the summer and autumn months in 1963 were also examined. Changes at a station of more than 12 mm in 12 hours were observed whilst in some synoptic situations the differences between precipitable water values at radiosonde stations gave spatial variations of the order of 1 mm per 10 nautical miles. Since the data were obtained from the normal radiosonde ascents made at intervals of 12 hours, it was not possible to determine the absolute variations over time intervals as short as

one hour or over space intervals as small as 10 nautical miles. Some idea of the effect of shortening the space interval was obtained by examining those occasions when the mean 700 mb wind speed between consecutive radiosonde ascents was very weak. Only one month, June 1963, was examined but from these very limited data it was noted that a change of 10 mm in the precipitable water parameter could occur when the column, if advected with the 700 mb wind, had only moved about 50 nautical miles: this corresponds to a spatial variation of 2 mm per 10 nautical miles.

The absolute variations over small time and space intervals are therefore occasionally likely to be considerably in excess of 1 mm per hour and 2 mm per 10 nautical miles, and these variations assume considerable importance when the representativeness of individual observations in a humidity analysis is being considered.

Estimates of precipitable water from surface observations over the sea.—Since ship surface observations over the Atlantic greatly outnumber the available upper air observations, the possibility of obtaining estimates of precipitable water based on surface observations is an attractive proposition. All hours in the five-month period June to October 1963 for which a radiosonde ascent was available at the ocean weather stations 'I', 'J' and 'K', were classified into three categories representing the weather states:

- (a) no precipitation at the time of the upper air observation or in the preceding hour,
- (b) showery precipitation,
- and (c) precipitation other than showers.

The surface parameters extracted for these occasions were the dry-bulb temperature, dew-point and sea temperature at the time of the upper air observation and the wind direction at the same time and also 6 hours earlier. The precipitable water (1000–500 mb) was computed from the appropriate radiosonde ascent.

Table II shows the extent to which precipitable water is correlated with the surface parameters and with the three derived parameters, the dew-point

TABLE II—CORRELATION BETWEEN PRECIPITABLE WATER (1000–500 MB LAYER) AND SPECIFIED SURFACE PARAMETERS AT 0000 AND 1200 GMT AT OCEAN WEATHER STATIONS 'I', 'J' AND 'K' IN JUNE TO OCTOBER 1963.

	0000 GMT				1200 GMT			
	All cases	No ppn	Shower type ppn	Other ppn	All cases	No ppn	Shower type ppn	Other ppn
Surface parameters								
Dew-point	+0.68	+0.70	+0.80	+0.66	+0.69	+0.69	+0.73	+0.67
Dew-point depression	-0.49	-0.44	-0.50	-0.42	-0.41	-0.35	-0.23	-0.38
Sea temperature	+0.40	+0.50	+0.54	+0.44	+0.46	+0.54	+0.58	+0.43
Dry-bulb temperature	+0.52	+0.58	+0.76	+0.61	+0.53	+0.59	+0.68	+0.53
Difference between dry-bulb and sea temperature	+0.42	+0.37	+0.62	+0.47	+0.33	+0.28	+0.36	+0.39
Difference between sea temperature and dew-point	-0.52	-0.44	-0.73	-0.52	-0.46	-0.37	-0.43	-0.51
Wind direction	+0.13	+0.06	+0.14	+0.14	+0.03	+0.00	+0.05	+0.09
Wind direction 6 hours earlier	+0.14	+0.08	+0.20	+0.10	+0.04	+0.00	+0.27	+0.00
Total number of cases	447	300	47	100	450	302	54	94

depression, the difference between dry-bulb and sea temperatures and the difference between sea temperature and the dew-point. The 0000 GMT data were examined independently of the 1200 GMT data and it will be noted that the surface parameter most highly correlated with the precipitable water at both observation times and for each of the three weather states is the dew-point, the correlation coefficients varying between 0.66 and 0.80. Though these coefficients might be considered rather low to form the basis of a quantitative analysis of precipitable water, comparison with Table I and Figure 2 shows that these coefficients are considerably higher than the autocorrelation coefficients over periods of 12 hours or more and seem likely to be higher than the autocorrelation for periods as short as 6 hours. On occasions when an upper air observation is missing at a specific synoptic hour it would appear, therefore, that an estimate based on the value of the surface dew-point and the state of the weather would probably be a better estimate than the previous observation of precipitable water for that place.

There seems little reason to suggest that the correlation between precipitable water and dew-point would be markedly different at other seasons of the year but this aspect would have to be examined if it became necessary to use operationally the precipitable water fields obtained in this way. At the same time, examination of the limited data available for these five months suggests that higher correlation could be achieved by taking into account the state of the sky: subdivision of the data into categories representing the state of the sky as well as the state of the weather would therefore appear desirable, though it should be emphasized that a much greater volume of data would be required in order to achieve this greater discrimination. For interest Table III has been included to give an estimate of precipitable water in millimetres for the observed dew-point and present weather state at 0000 GMT and 1200 GMT,

TABLE III—ESTIMATED PRECIPITABLE WATER (1000–500 MB LAYER) FOR OBSERVED SURFACE DEW-POINTS AND WEATHER STATES AT 0000 AND 1200 GMT AT OCEAN WEATHER STATIONS 'I', 'J' AND 'K' IN JUNE TO OCTOBER 1963

Surface dew-point °C	Weather state					
	No precipitation at time of observation or during previous hour		Showery precipitation at time of observation or during previous hour		Precipitation other than showers	
	0000 GMT	1200 GMT	0000 GMT	1200 GMT	0000 GMT	1200 GMT
	<i>millimetres</i>					
1	4.5		5.8		6.5	
2	5.7		6.9		7.9	
3	6.9	7.6	8.1	9.0	9.3	7.2
4	8.1	8.7	9.2	9.8	10.7	8.7
5	9.3	9.9	10.3	10.6	12.1	10.2
6	10.5	11.0	11.5	11.4	13.5	11.8
7	11.7	12.1	12.6	12.3	14.9	13.3
8	12.9	13.2	13.7	13.1	16.3	14.8
9	14.1	14.3	14.9	13.9	17.6	16.4
10	15.3	15.5	16.0	14.7	19.0	17.9
11	16.5	16.6	17.1	15.5	20.4	19.4
12	17.7	17.7	18.3	16.4	21.8	20.9
13	18.8	18.8	19.4	17.2	23.2	22.5
14	20.0	20.0	20.5	18.0	24.6	24.0
15	21.2	21.1	21.7	18.8	26.0	25.5
16	22.4	22.2	22.8	19.6	27.4	27.1
17	23.6	23.3	24.0	20.5	28.8	28.6
18	24.8	24.4	25.1	21.3	30.1	30.1
19	26.0	25.6	26.2	22.1	31.5	31.6

of a millimetre and the estimates, based on surface ship observations and Table III, are given to the nearest whole millimetre. It will be noted that no 1200 GMT sounding was available for Lajes in the Azores and that the humidity data on the sounding from ocean weather station 'C' (approx 53°N, 35°W) were insufficient to permit a value of precipitable water to be computed for the layer 1000–500 mb. Extremely dry air had been carried previously from the British Isles towards ocean weather station 'J' and it will be seen that in this part of the map, the computed value is rather low compared with the estimate derived from the surface observations; for other ocean weather stations the estimates are fairly close to the computed values.

Estimates of precipitable water from the 1000–500 mb thickness.—

The relationship between the 1000–500 mb precipitable water and the 1000–500 mb thickness was examined using the data for the same five months as the previous section, namely June to October 1963, for the three ocean weather stations 'I', 'J' and 'K'. Table V shows the correlation between precipitable water and thickness for all occasions at 0000 GMT and 1200 GMT as well as for the three weather state categories previously defined. The correlation is highest, 0.71, for those occasions when precipitation other than showers was occurring: for the other two weather states the correlation coefficients are lower than those obtained with some of the more significant surface parameters, e.g. dew-point and dry-bulb temperature.

TABLE V—CORRELATION BETWEEN PRECIPITABLE WATER (1000–500 MB LAYER) AND THICKNESS (1000–500 MB) AT 0000 AND 1200 GMT AT OCEAN WEATHER STATIONS 'I', 'J' AND 'K' IN JUNE TO OCTOBER 1963

	0000 GMT				1200 GMT			
	All cases	No ppn	Shower type ppn	Other ppn	All cases	No ppn	Shower type ppn	Other ppn
Correlation coefficient	+0.59	+0.57	+0.69	+0.71	+0.61	+0.60	+0.63	+0.67
Number of cases	447	300	47	100	450	302	54	94

There is, however, another aspect which should be kept in mind when considering the possible use of the thickness field in this problem. It might become necessary to use a field of precipitable water more akin to that of maximum precipitable water on the assumption that the air column involved in the rain process is completely saturated. The 1000–500 mb thickness charts could provide such a field of maximum precipitable water by using a table such as Table VI, which gives precipitable water values for specified thickness values assuming that the air column is saturated with a lapse rate following the saturated adiabatic: some adjustment could be made when the stability of the air mass is markedly different from this.

TABLE VI—PRECIPITABLE WATER (1000–500 MB LAYER) FOR AN AIR COLUMN WHICH IS SATURATED AND IN NEUTRAL EQUILIBRIUM AND WITH INDICATED THICKNESS (1000–500 MB)

1000–500 mb thickness (decametres)	510	516	522	528	534	540	546	552	558	564	570
Precipitable water (mm)	7	9	11	13	16	20	24	29	35	42	50

Conservatism of precipitable water.—In an earlier section reference was made to the observed temporal changes in precipitable water at a fixed point and to the observed spatial changes at a fixed synoptic hour. It is interesting, as well as useful, to attempt to determine what changes take place in the 1000–500 mb precipitable water parameter, following the air motion at 700 mb. By constructing 700 mb trajectories of 24-hour duration, originating at radiosonde stations in the British Isles and neighbouring sea and land areas, it is possible to compare the precipitable water at the start of the trajectory with a later ‘observed’ precipitable water value, whenever the trajectory passes sufficiently close to a radiosonde station. Such an experiment was carried out with data from June 1963, using British radiosonde stations as control stations for providing the ‘observed’ precipitable water values for comparison. Whenever one of the 700 mb trajectories constructed as above passed within 100 nautical miles of a control station the following details were noted:

- (i) The time of nearest approach;
- (ii) Whether the nearest approach distance was
 - (a) 50 nautical miles or less
 - or (b) between 50 and 100 nautical miles;
- (iii) The period of the trajectory up to the nearest approach time in the four categories:
 - (a) up to 6 hours,
 - (b) more than 6 but not more than 12 hours,
 - (c) more than 12 but not more than 18 hours,
 - or (d) more than 18 but not more than 24 hours.

The ‘observed’ precipitable water value was that value obtained from the upper air ascent closest in time to the time of closest approach; in those cases, therefore, when the time of closest approach fell midway between consecutive upper air observations, there were two ‘observed’ values for comparison. There were also some trajectories which passed sufficiently close to more than one control station and on these occasions, as well, more than one ‘observed’ value was available for comparison. In all, 476 comparisons were made, giving a correlation coefficient of 0.60 between ‘initial’ and ‘observed’ precipitable water. When the restriction that the trajectory should be for not more than 12 hours duration is imposed the number of cases is 269 with a correlation coefficient of 0.63. The correlation is 0.65 (281 cases) when the occasions are restricted to those when the time of nearest approach is within 4 hours of the time of the ‘observed’ precipitable water, and the correlation coefficient reached 0.68 (142 cases) if this time interval is reduced to 2 hours or less. When this last restriction is coupled with the restriction that the trajectory had to pass within 50 nautical miles of the control station, the number of cases drops to 89, giving a correlation coefficient of 0.65. Bearing in mind the size of the variations in precipitable water previously discussed, namely 1 mm per hour and 2 mm per 10 nautical miles, these correlation coefficients seem high enough to support the suggestion that precipitable water is a fairly conservative parameter.

Computed values of precipitable water from the previous upper air observation time, advected with the appropriate 700 mb wind, could therefore provide, especially over the Atlantic, approximate values of precipitable water which could be utilized in the analysis.

Conclusions.—To provide satisfactory forecasts of rainfall it is important to know the distribution of moisture in considerable detail in addition to that of vertical motion. It is suggested that charts of precipitable water be used to define the moisture patterns; however, the present synoptic upper air observations are insufficient to provide the details of the smaller-scale patterns in the moisture fields and should be supplemented by estimates based on surface observations and on previous upper air observations displaced with the appropriate 700 mb winds.

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TECHNIQUES OF TEMPERATURE AND WIND SOUNDING WITH THE SKUA METEOROLOGICAL ROCKET

By R. ALMOND

History.—Firings of the first development rounds of the SKUA Meteorological Rocket commenced in March 1963. Initial failures were associated with the delayed ignition of the sustainer motor, and this trouble was rectified by October of that year. It had been planned that firings would start in the Outer Hebrides at the commencement of the International Years of the Quiet Sun period in January 1964, and with this end in view development firings were completed at this station.

The first signal from a payload ejected from the rocket at apogee was heard on 10 November 1963, from about 35 kilometres altitude, and the first temperature measurements from a sonde were obtained one month later on 9 December 1963, from an altitude of 42 km. Production round firings started in January 1964, and continued until March when the programme was halted because of a dramatic increase in failure rate. A further development stage covering June to November 1964, was held at the Ministry of Aviation range in Wales, and was based on deliberate spinning of the vehicle up to a maximum rate of 12 rev/second. Five good trajectories were obtained from six rounds, the failure being due to motor trouble and not to instability. This was considered good proof that the Hebrides failures attributed to a rocket instability phenomenon called 'roll yaw lock-in', i.e. destructive interaction between the roll and yaw features of the vehicle, had been overcome.

The spin feature was therefore incorporated in the rounds prepared for the second Hebrides campaign, covering the period January to April 1965. Although a few failures resulted during this period, it is felt that a very successful sounding rocket has now been developed. Photographs of the rocket launcher and the sonde are shown in Plates I–III.

The rocket vehicle.—SKUA 1 which has been used for all soundings to date, will carry a 4.5-kilogram payload to an altitude of 70 km for an 85°-elevation firing. It has a payload section volume of 8.2 decimetre³, is 2.3 metres long and 13 centimetres in diameter, and has an all-up weight of 37 kg. The motor is a solid propellant end-burning type. Low dispersion is achieved by launching the rocket from a steel tube, 10 m long and 53 cm in diameter,

using a boost rocket. The latter forms the central portion of a carriage structure and piston, on top of which the fins of the main rocket rest, under gravity only, in special wedges. The forward end of the rocket is aligned axially by a foamed-plastic sabot. The carriage has wheels which contact the inner surface of the launcher tube, and houses fins and two 2-m parachutes for guidance and safe return to ground, ensuring its usability for further firings. The boost thrust is 1800 kg for 0.2 seconds, yielding a tube exit velocity of 107 m/s. The main rocket is ignited at the same instant as the boost and burns for 30 s, after which time a height of 16.5 km and a speed of 1220 m/s have been reached. A thermal switch operates at this point, starting a delay clock with a 105-s running period, at the end of which a small rocket is fired applying thrust to a piston which separates the payload from the rocket body at a speed of 7.6 m/s having sheared the nose-cone retaining pins. This timing of 135-s from launch coincides with the 70-km apogee of the rocket.

Launcher settings to achieve effective 85°-elevation firings are determined from ballistic wind correction data. Wind structure is measured over the full burning range, i.e. 16.5 km and weighting factors are applied to the mean winds of six appropriate layers within this depth of atmosphere. This gives a total ballistic wind to which the unit wind effect of 0.598° per m/s is applied. Half the 'weighting' is taken up in the first 370 m of the 16.5 km considered.

The rocket can be 'skin-tracked' by the standard Meteorological Office wind-finding radar to a slant range of 50 km, and this is sufficient to define the trajectory and supply accurate 'laying-on' angles for parachute acquisition at apogee. Figure 1 shows trajectories for varying angles of elevation.

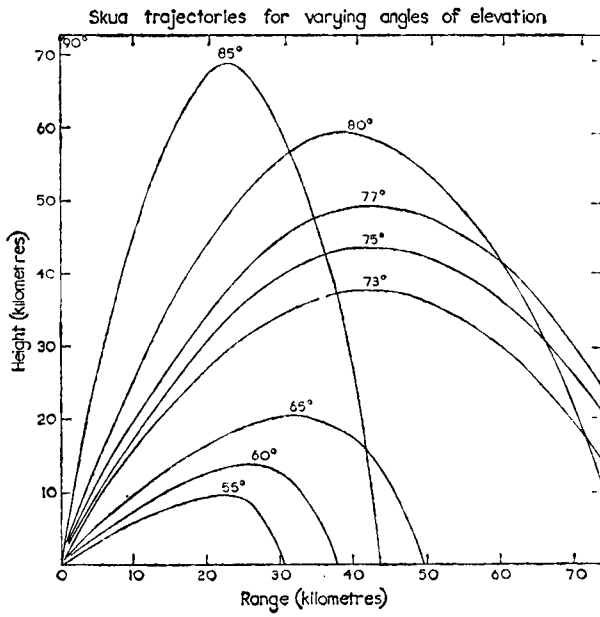


FIGURE 1—SKUA TRAJECTORIES FOR VARYING ANGLES OF ELEVATION

SKUA 2, now undergoing development trials, is an improved performance version of SKUA 1. It has an apogee of 100 km for an 85°-elevation firing, achieved by only 3 s extra burning time, necessitating a motor elongation of only 11 cm and increased all-up weight of 2 kg. The initial meteorological

payload is high-altitude radar chaff (85 to 60 km) plus temperature sonde with parachute (65 to 15 km). A standard chaff load for SKUA 1 is already fully developed and tested, forming an alternative payload to the sonde.

The meteorological payload.—The meteorological payload is almost invariably the temperature-measuring sonde and parachute yielding wind/temperature/height data between 65 and 15 km. It must be capable of rocket ascent to 70 km, full deployment, and finally yield the telemetry data for at least one hour with negligible circuit temperature and voltage coefficient errors. The parachute must give reflected primary radar pulses of sufficient strength to produce automatic range, elevation, and azimuth presentation data at the ground station to at least 140-km slant range.

Sonde circuit.—A low-power (30 milliwatt) single transistor oscillator coupled to a quarter-wave aerial provides the radio frequency carrier operating at a pre-set frequency in the 27.5 to 28-megacycles/second meteorological band.

This carrier is frequency modulated with a deviation of ± 20 kc/s by an audio-frequency signal within a band 700 to 1000 c/s. The variation of the audio frequency is a measure of atmospheric temperature. This variation is produced by the temperature element which forms a variable resistance arm in a twin-T bridge oscillator.

A resistive dividing network across a stabilized voltage supply is capacitatively fed from the output of the oscillator emitter follower, yielding the correct bias and A/F signal for a variable capacity diode which produces the F/M swing of the carrier.

A two-section dry battery provides separate supplies for A/F and R/F sections, the A/F supply being stabilized by Zener diodes.

The R/F circuit has two tuning facilities, one capacitative for frequency setting, and one inductive for power matching into the quarter-wave aerial.

Construction.—The temperature element is a flat double open spiral of spiralized tungsten wire supported by plastic monofilament spokes, in an aluminized resin-bonded fabric 8.9-cm diameter ring. The wire, of diameter 13.5 microns, has a pitch of about 90 microns and a spiralized diameter of about 200 microns. This enables a resistance of 3100 ohms (at 0°C) to be mounted compactly and safely. The resulting actual length of wire is 7.72 m. The element ring is grooved on the inside to take a spring clip, which forms a resilient mount and is attached to a spring-loaded telescopic deployment shaft.

During the ascent the temperature element is held on a foamed-plastic cushion protected by an element cap which carries a cord harness and release pin. These are removed when the rocket nose-cone has separated 1 m from the sonde on parachute deployment, since the cord is attached to an eye-bolt in the apex of the nose cone.

The temperature element is then carried by its deployment shaft to a point 13 cm from the main sonde body and at the same time power is applied to the circuit. The exposed temperature element is now the lowest point of the sonde assembly as it descends by parachute. The canopy of the parachute is 4.5 m in diameter and has alternate panels of metallized and unmetallized silk making it a passive radar target. A strop between the apex of the shroud lines and the sonde suspension point houses the quarter-wave transmitter aerial.

The average parachute fall rates from different heights are given in Table I.

TABLE I—AVERAGE PARACHUTE FALL RATES

Height <i>kilometres</i>	Fall rate <i>metres/second</i>	Time elapsed	
		<i>minutes</i>	<i>seconds</i>
70	225	zero	
65	160		10
60	125		50
55	90	1	40
50	65	2	40
40	32	6	15
20	4.5	40	
14	3.7	60	

The main circuit components are housed in an all-metal chassis and protected with a silicone rubber coating before being completely encapsulated in rigid poly-urethane foam. To prevent twisting of the strop and parachute shroud lines a small swivel link is placed between them. This is required because of the spin feature of the rocket which also necessitates the dynamic balancing of the sonde.

Temperature corrections.—Measurements were made in the National Physical Laboratory low-density wind tunnel at the required density/speed combinations, and with and without radiation, in order to determine the law governing temperature rise above the true air temperature in the falling sonde temperature element. Dynamic heating and radiation errors are complicated by the different flow régimes (free molecular, slip, and continuum) which are encountered between 70 and 20 km, and also by the fact that the temperature element seems to behave as if possessing a dimension factor intermediate between the diameter of the wire and that of the coil. The dynamic heating correction is found to be unaffected by the yaw angle, at least up to 45°, but the radiation correction increases from a minimum at incidences normal to the plane of the double spiral to a maximum at high incidence angles, being eventually cut off by the shielding effect of the temperature-element mounting ring. From a known radiation error at 50 km, errors below this level are calculated assuming the relationship :

$$\Delta T_i \propto \frac{1}{\sqrt{(V\rho)}}$$

where

ΔT_i = radiation error

V = air velocity relative to sonde

ρ = air density.

Some values for radiation and dynamic heating corrections are given in Table II.

TABLE II—RADIATION AND DYNAMIC HEATING CORRECTIONS

Height <i>kilometres</i>	Radiation correction (45° incidence) <i>degrees C</i>	Dynamic heating correction (0-45° incidence, i.e. all practical angles) <i>degrees C</i>
20	1.5	0.0
50	3.5	2.1
60	6.5	7.9
65	10.0	15.3

The radiation corrections have been evaluated on the basis of an average angle of exposure of 45°, resulting from the swing of the sonde, and must include a term, not given in the table, based on the albedo of the surface beneath.

The relationship of the element with respect to free molecular flow and continuum flow was found by the wind-tunnel experiment and from this work recovery factors have been found to apply to the full adiabatic rise for air brought to rest in continuum flow. A factor of 1 is applied up to 50 km, and this increases to 1.3 at 70 km. The lag correction is considered negligible. No error could be detected during wind-tunnel measurements, when the radiation source was switched off, indicating that the lag must be less than 1 second which is the decay period of the radiation lamp. Even at the lowest pressures, equivalent to a 65-km height, it was deduced theoretically that with a fall speed of 200 m/s in a lapse of 5 degC/km the error would not exceed 0.5 degC.

The power dissipated in the temperature element is less than 0.015 milliwatts, and this is spread over 772 cm of wire, yielding a negligibly-small self-heating error. Because of the long length of wire involved, end effects are also negligible.

Height and wind data.—Data from the automatic tracking of the sonde parachute is converted to give heights and winds.

Ground equipment.—

Sonde.—A standard Meteorological Office radiosonde ground-recording equipment is used which automatically produces a graphical record of periodicity/time at a maximum sampling rate of 40 readings per minute and accuracy ± 1 periodic-time unit (i.e. ± 0.1 c/s at 1000 c/s, ± 0.05 c/s at 700 c/s).

Radar.—The standard Meteorological Office auto-follow wind-finding radar is used both to 'skin-track' the rocket for trajectory details, and to track the sonde parachute for wind/height data.

Computation.—Sonde periodicities are converted into temperatures by means of a calibration graph and all the necessary corrections applied. A common time-scale is used for the radar and rocketsonde ground equipments, enabling correlation between the two sets of data. Finally, corrected temperatures, associated with radar heights and a tie-on radiosonde pressure, are used to compute pressures and densities to the top of the ascent. The full wind structure is also computed as mentioned above.

Personnel requirement.—The firing of a SKUA round at the Royal Artillery Guided Weapons Range, South Uist, Outer Hebrides, involves three teams of personnel. The Army provides four people in the range safety roll who can be called on for each firing after rocket preparation work has been completed. Their duties are: range surveillance, launcher setting check, all safety checks, and finally giving permission to fire.

The RAF team of four is responsible for all rocket handling, preparation (apart from the payload), loading, launching, boost recovery, a certain amount of refurbishing, and assistance by one member in radar operation and maintenance. The Meteorological Office team of four is responsible for sonde preparation, ballistic wind measurement, launcher-setting calculations, radar and sonde ground equipment operation and maintenance, computation of the sounding and preparation of the 'ROCOB' message. Some of the personnel are shown in Plate IV. The Bristol Aerojet Company, who are the rocket manufacturers, have supplied trials officers throughout the development stages of the project.

Co-operation at all times has been excellent and, as our hosts, the Army have made our visits to South Uist at all times trouble free.

RESULTS FROM THE SKUA METEOROLOGICAL ROCKET PROGRAMME

By S. F. G. FARMER

Introduction—During the past year and a half the SKUA rocket has been used by the Meteorological Office to measure stratospheric winds and temperatures. The firing programme has been largely confined to the two winter seasons. The first operational firing campaign was held at the Royal Artillery Range on the island of South Uist in the Outer Hebrides, in January and February 1964, coinciding with the start of the International Years of the Quiet Sun. This was followed by a short series of firings made at Aberporth in the late summer of 1964, during further development work on the rocket. The third and longest firing period started in early January 1965 at West Geirinish, South Uist, and was not completed till late April. Up to the present time (August 1965) 33 successful flights have been made with nearly 90 per cent of the data recovered on these occasions.

The main features of the stratospheric wind and temperature structure have already been established by indirect methods of measurement and in more recent years by rocket soundings in the U.S.A. Meteorological Rocket Network. These features have been corroborated by the SKUA rocket soundings and in addition some light has been shed on the longitudinal variations in the winter stratospheric circulation.

The data.—The apogee of SKUA is usually about 65 or 70 kilometres. The method of temperature measurement, immersion thermometry using a very fine tungsten wire, cannot be used above this height because of the very large radiation and dynamic heating corrections. The usual method of wind measurement likewise has an upper limit of about 60 km, because the parachute fails to respond to vertical wind shears when falling at high speed. However, the whole of the stratosphere is sampled and also the lower part of the mesosphere.

At West Geirinish the stratospheric temperature minimum which occurs at about 25 km, has been found to be well defined on many occasions in mid-winter (see Figure 2). On some descents, temperatures below -80°C have been recorded. These low values are supported by the Stornoway radiosonde ascents, a temperature of -80°C or below being reported on four days during January and February this year.

Above this minimum the temperature increases to the stratopause. The mean height of this temperature maximum is 50 km, and the temperature there may sometimes exceed 0°C . The mesosphere has a small positive lapse rate, with the temperature falling towards a weakly-defined mesopause.

Analysis of the winter circulation and spring reversal.—A stormy period dominated the first two months of the year. The large day-to-day variability of the stratospheric temperatures is demonstrated by the three soundings made on 15, 18 and 20 January 1965 (see Figure 1). At the beginning of this five-day period the stratopause was unusually warm ($+12^{\circ}\text{C}$) and situated just below 50 km. Three days later there had been a cooling of 30°C at this level, the stratopause now being situated at only 40 km. with a temperature of -17°C . Two days later it was re-established at 51 km with a temperature of 0°C . Throughout this period the winds were fairly constant in direction from about 250° , but there were large changes in speed. Similar changes had been observed in early 1964, but less comprehensively.

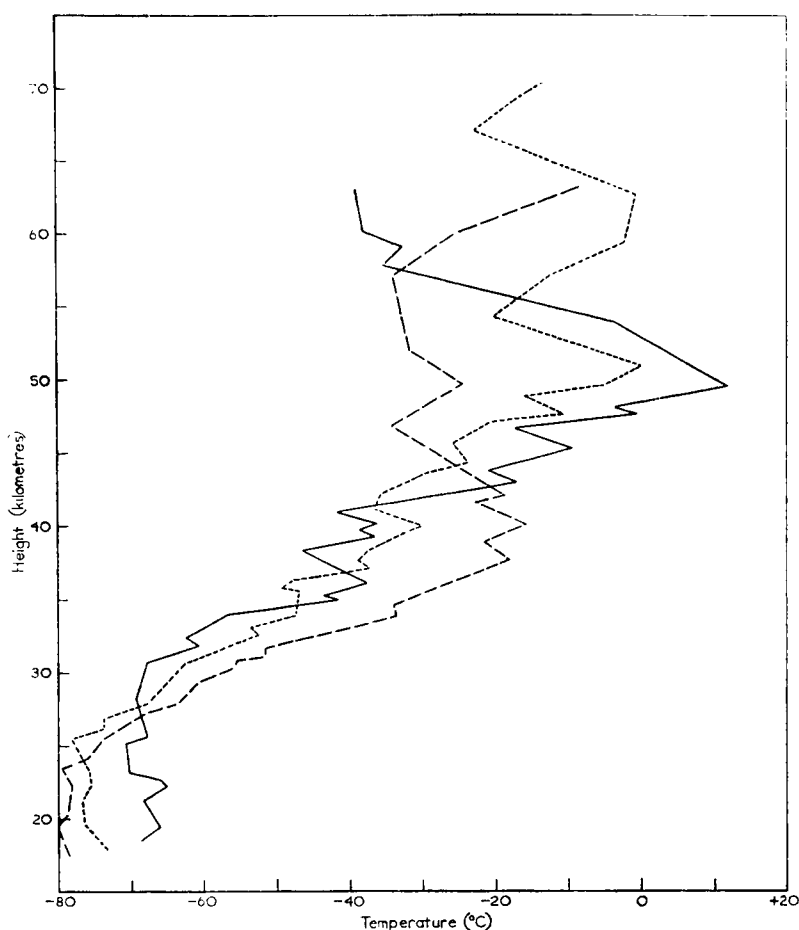


FIGURE 1—TEMPERATURE SOUNDINGS AT SOUTH UIST DURING JANUARY 1965

— 2150 GMT on 15 January
 - - - 2137 GMT on 18 January
 - - - 1948 GMT on 20 January

An adequate description of these changes in terms of synoptic systems passing over West Geirinish has not been possible. Thermal winds calculated for 5-km thick layers have commonly been found to be reversed between successive firings. Instantaneous advective heating rates, which assume no radiative or adiabatic heating, are often an order of magnitude larger than the mean rates of change of temperature observed between soundings.

From mid-March onwards there was a much more regular change with a slow increase of temperature at all levels and a slackening of the wind. This is illustrated in the two time cross-sections (Figures 2 and 3) which have been supplemented in the lower stratosphere by data from the Stornoway radiosonde ascents.

A major stratospheric warming had its inception near the British Isles during the first week of March 1965. The rocketsonde sounding of 1 March was unusually warm at 34 km (-24°C), and on 3 and 5 March temperatures of -43°C and -32°C were recorded at 10 mb by the Stornoway midday ascent. Warming events were observed at Crawley and Berlin at about the same time. The warm centre became clearly identifiable at 10 mb on 9 March. In the next three weeks it was tracked across Europe and Asia before turning north towards the pole and weakening. The temperature of the 10 mb centre rose as high as -17°C .

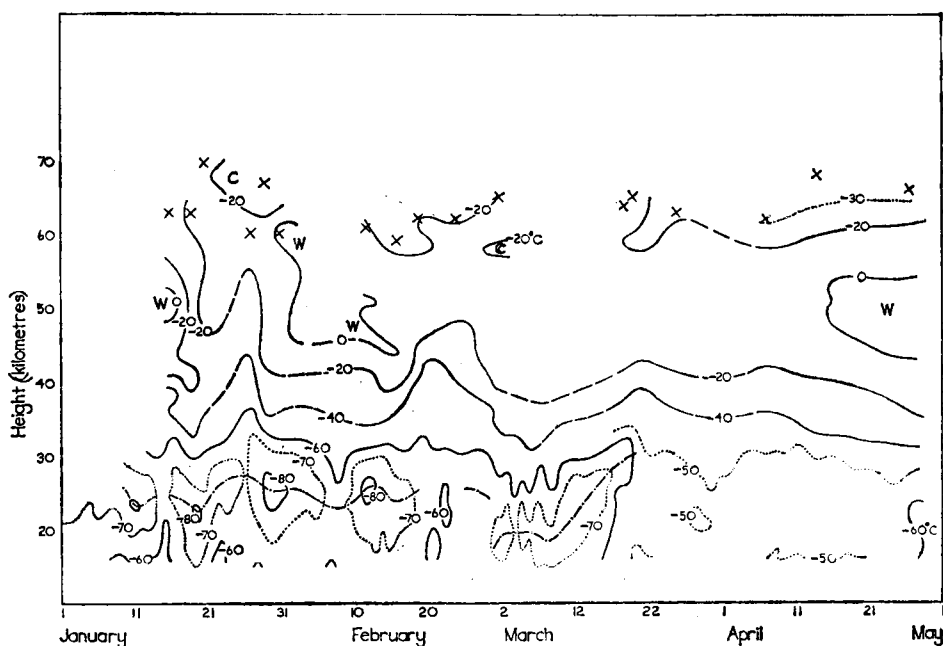


FIGURE 2—STRATOSPHERIC TEMPERATURE CROSS-SECTION FOR WEST GEIRINISH DURING WINTER AND SPRING 1965

- x Upper limit of rocketsonde data
- C Cold centre W Warm centre
- - - Stratospheric temperature minimum

Intermediate isopleths are shown by a dotted line and pecked lines indicate where data were incomplete.

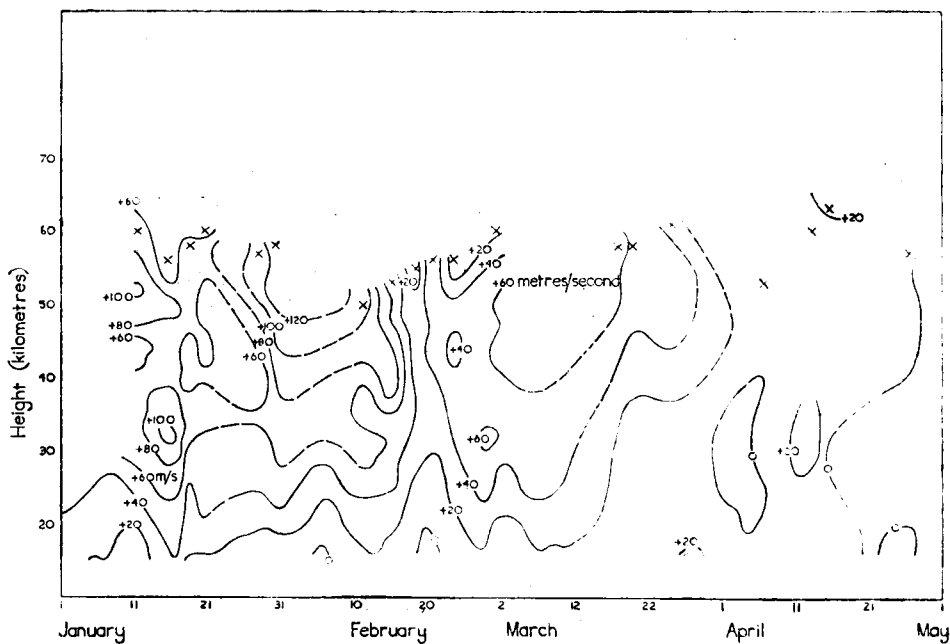
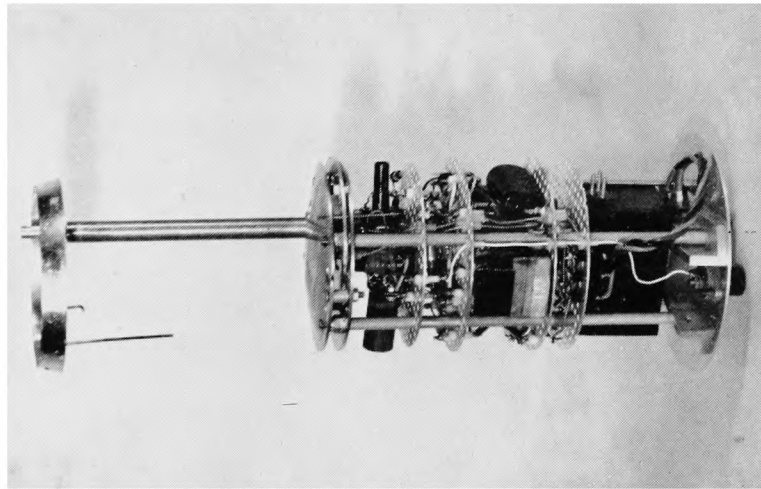
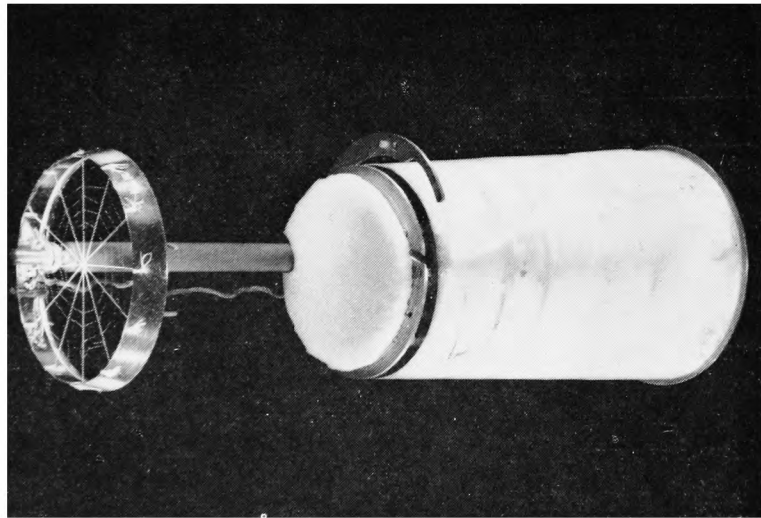


FIGURE 3—STRATOSPHERIC ZONAL WIND CROSS-SECTION FOR WEST GEIRINISH DURING WINTER AND SPRING 1965

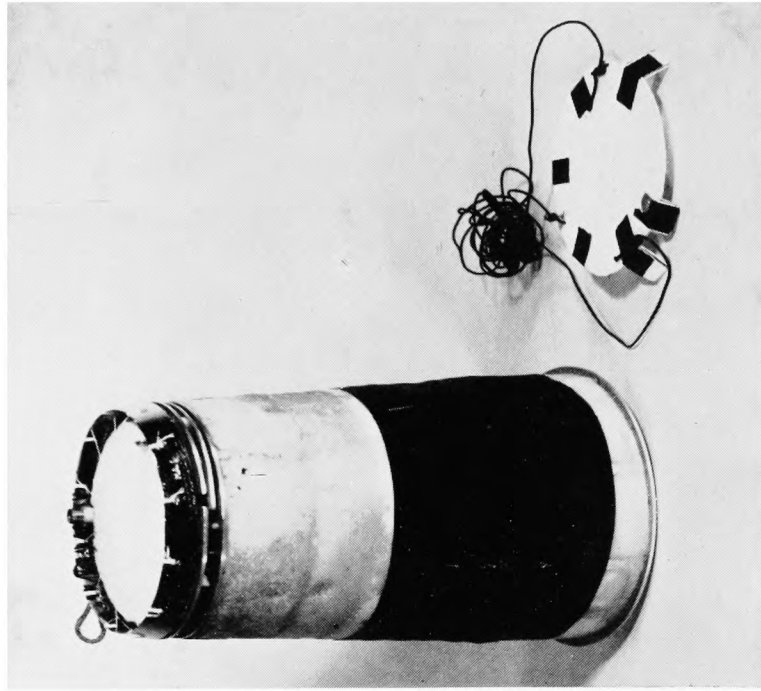
- x Upper limit of rocket wind data
- Pecked lines indicate where data were incomplete.



(a) Before encapsulation showing dis-
position of circuit components and
battery.



(b) Encapsulated with temperature
element extended.



(c) Encapsulated with temperature
element stowed for ascent.

PLATE I—ROCKETSONDE FOR THE SKUA METEOROLOGICAL ROCKET

See page 327.



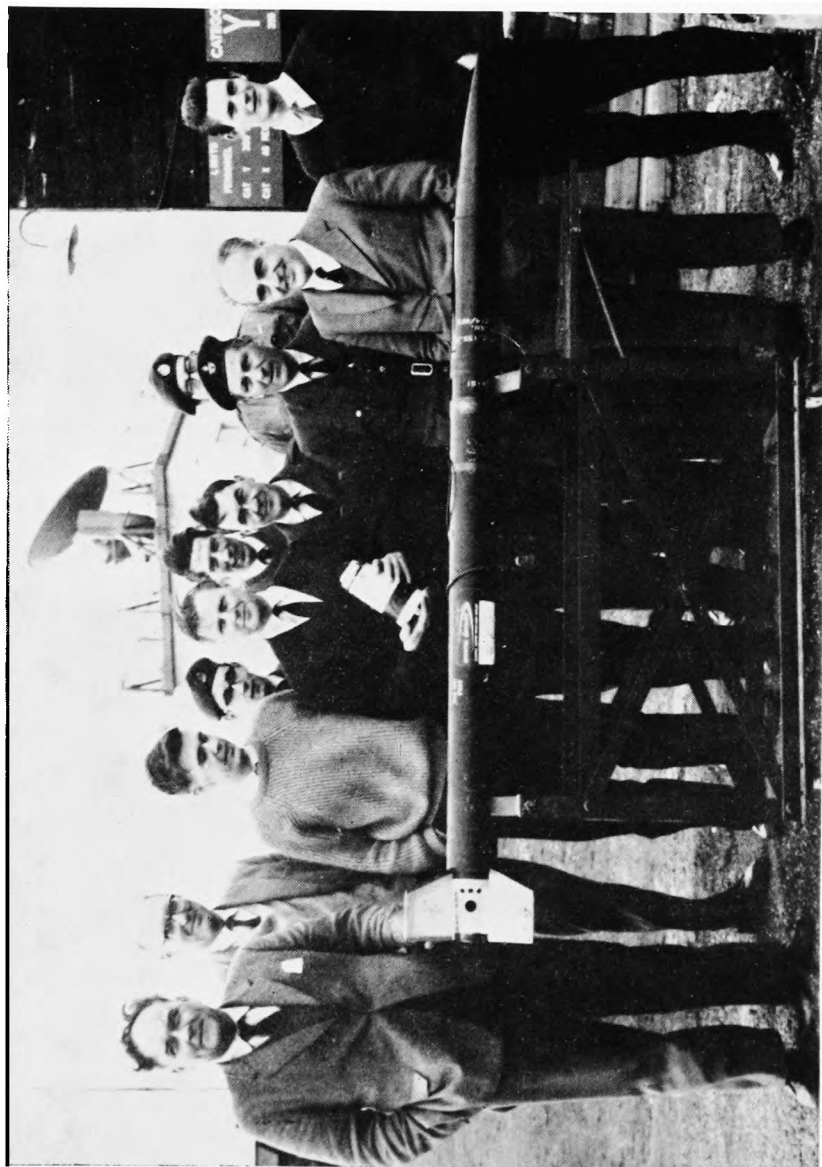
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PLATE II—SKUA METEOROLOGICAL ROCKET LAUNCHER VEHICLE WITH TUBE IN STOWED POSITION



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PLATE III—SETTING THE TRANSMITTER FREQUENCY OF THE ROCKETSONDE
See page 327.



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PLATE IV—THE SKUA ROCKET WITH DEVELOPMENT AND LAUNCHING TEAMS

From left to right: Mr. D. N. Hoare and Mr. W. T. Fisher, Bristol Aerojet Ltd.; Mr. S. F. G. Farmer, Met. Office; Cpl. A. Mann, RAF; Mr. R. Almond and Mr. A. F. Lewis, Met. Office; Chief Technician B. Potts, S/Ac. D. White and W/O G. Brewis, RAF; Dr. R. Frith and Mr. B. Greener, Met. Office. (see p.331).

Although westerly winds still persisted in the stratosphere for the next month they became steadily weaker and temperatures at all levels showed a marked rise. A light easterly was first observed at Crawley on 26 March and at Stornoway five days later. However, even as late as 26 April, when the last SKUA sounding was made, a very light westerly was still present at the stratopause.

The autumnal reversal and the onset of the winter circulation were also observed in 1964 (see Figure 4). Four soundings were made at Aberporth. On 26 August 1964 the winds were very light up to 43 km, the radar track of the parachute unfortunately being incomplete. By 23 September the west winds were established down to 30 km. A week later the westerlies were present throughout the stratosphere, with a maximum of 37 metres/second at 51 km. The final sounding on 9 November showed westerlies in excess of 100 metres/second between 47 and 52 km.

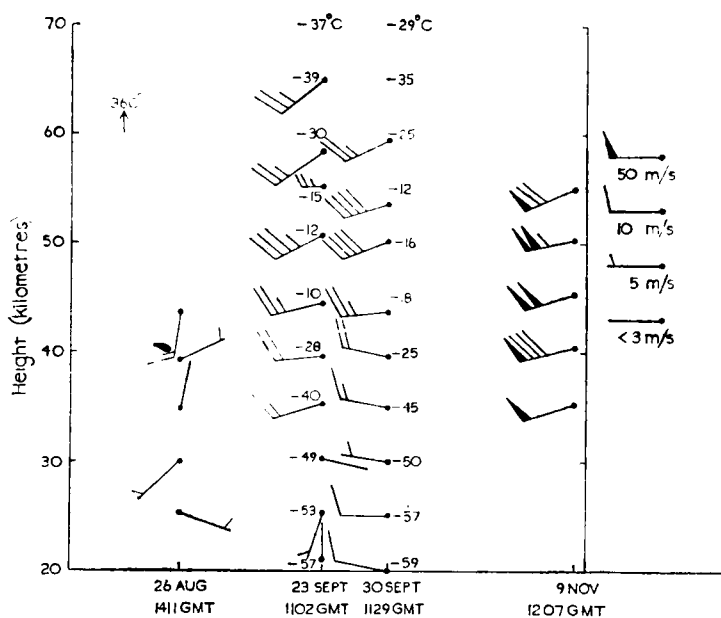


FIGURE 4—AUTUMNAL REVERSAL OF STRATOSPHERIC WINDS FOR ABERPORTH IN 1964

Temperatures are shown for the two firings in September.

The nature of the spring reversal is in marked contrast to that observed at lower latitudes,¹ where the easterly winds have first appeared above 50 km and then propagated downwards at 1 to 5 km/day. However, even at these low latitudes, easterly winds have been observed to propagate upwards from 30 km on occasions. Insufficient data are available to suggest the form of the autumnal reversal in 1964.

Longitudinal variations in the stratospheric circulation.—The monthly mean zonal wind components and temperatures have been calculated for West Geirinish (Table I). The number of soundings varies from 11 in the two January months to 4 in each of March and April 1965. Standard deviations have been quoted where there are four or more measurements available, although the sample is small for all levels.

TABLE I—MEAN MONTHLY TEMPERATURES AND ZONAL WINDS FOR WEST
GEIRINISH ($57^{\circ}21'N$, $07^{\circ}23'W$)

(a) Mean monthly temperatures

Height km	January				February				March				April			
	<i>n</i>	\bar{T}	σ	<i>T</i>	<i>n</i>	\bar{T}	σ	<i>T</i>	<i>n</i>	\bar{T}	σ	<i>T</i>	<i>n</i>	\bar{T}	σ	<i>T</i>
		<i>degrees C</i>				<i>degrees C</i>				<i>degrees C</i>				<i>degrees C</i>		
70	1	-14		-30				-35				-42				-49
65	3	-23		-40				-39	2	-16		-39	2	-31		-38
60	8	-15	13	-44	3	-17		-40	4	-18	2	-34	3	-22		-26
55	8	-22	12	-35	5	-8	2	-35	4	-11	4	-26	3	-7		-13
50	8	-16	14	-22	5	-10	5	-22	4	-11	4	-17	3	-1		-5
45	9	-20	11	-30	5	-14	9	-31	4	-12	3	-26	3	-7		-13
40	9	-31	10	-43	7	-31	10	-43	4	-29	10	-38	3	-20		-26
35	10	-53	13	-51	7	-45	4	-52	4	-46	11	-49	3	-33		-41
30	10	-70	6	-58	7	-65	3	-59	4	-54	4	-57	3	-47		-54

(b) Mean monthly zonal winds

	January				February				March				April			
Height km	<i>n</i>	\bar{U}	σ	<i>U</i>	<i>n</i>	\bar{U}	σ	<i>U</i>	<i>n</i>	\bar{U}	σ	<i>U</i>	<i>n</i>	\bar{U}	σ	<i>U</i>
	<i>metres/second</i>				<i>metres/second</i>				<i>metres/second</i>				<i>metres/second</i>			
60	2	+63		+59				+35	2	+27		+22	2	+11		-2
55	8	+85	27	+48	3	+24		+24	4	+51	7	+24	3	+9		+17
50	9	+88	21	+37	6	+62	27	+11	4	+55	6	+25	4	+9	6	+24
45	10	+78	21	+29	6	+65	26	+1	4	+45	10	+23	4	+10	6	+22
40	9	+68	16	+22	7	+58	19	-3	4	+39	9	+21	4	+7	7	+17
35	8	+75	10	+17	8	+54	15	0	4	+23	12	+17	4	+6	11	+13
30	9	+64	13	+10	8	+49	15	+8	4	+19	17	+13	4	+1	14	+8

n Number of observations.

σ Standard deviation (for $n \geq 4$).

\bar{T} Mean monthly temperature.

\bar{U} Mean monthly zonal wind.

T Temperature on first day of month at $57\frac{1}{2}^{\circ}N$, from proposed new COSPAR atmosphere (CIRA) (after Groves²).

U Zonal wind on first day of month at $57\frac{1}{2}^{\circ}N$, from proposed new COSPAR atmosphere (CIRA) (after Groves²).

These mean values have been compared with those given by Groves² for the first day of each month for $57\frac{1}{2}^{\circ}N$. These were obtained from an analysis of data obtained in the U.S. Meteorological Rocket Network and from grenade, pressure and density gauge experiments made elsewhere in the world. However the majority of measurements were made over the North American continent. Near the latitude of West Geirinish these means are strongly biased by data obtained at Fort Churchill, Canada and Fort Greely, Alaska.

In making this comparison it must be remembered that the data sample is small and that the monthly means are being compared with values for the first day of the month. Thus the difference of approximately $6^{\circ}C$ between the two sets of values for April is merely a reflection of the warming which continues throughout that month. However, earlier in the year when the seasonal change is small, the West Geirinish temperatures are significantly warmer for all heights above 40 km. At 40 km this difference is approximately one standard deviation ($10^{\circ}C$), and although smaller at 50 km appears to increase again above this. At 30 km, West Geirinish is much colder initially, this difference being due to the Aleutian high, which is a persistent climatological feature at 10 mb.

The difference in the zonal wind field is even more striking. In January the speeds observed at West Geirinish were very high and much more typical

of the stratospheric jet core over the North American continent, where the axis has a mean latitude of about 45°N . These strong winds continue through February into March.

The reversal of the zonal wind at 40 km on 1 February suggested by Groves' model has not been observed, although a slackening of the flow occurred on 18 and 20 February, 1965. The winds at all levels were then veered north of west. A similar weakening had been observed at balloon heights on 6 February.

Conclusion.—It is quite clear that there are important longitudinal variations in the mean winter circulation at least up to the stratopause and probably above. The asymmetry of the polar vortex already shown to exist by balloon soundings at 10 mb, is still apparent at greater heights. The launching of SKUA rockets on a regular basis from West Geirinish has provided the first measurements of these differences in subpolar latitudes over the European continent.

Acknowledgements.—The author wishes to acknowledge the continued help provided by the Ministry of Aviation and Bristol Aerojet Ltd., during all the development work, and the unfailing service provided by the Commandant of the Royal Artillery Range, South Uist for the Meteorological Office during the past two years.

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THE ANNUAL VARIATION IN THE JET STREAM ACROSS THE GREENWICH MERIDIAN

By W. G. RITCHIE and C. J. M. AANENSEN

By considering the direction of the average winds in the middle stratosphere, the year can be divided into two parts. Thus the monthly averages given by Graystone¹ for Crawley winds to 100,000 feet and for winds at Leuchars to about 90,000 feet show that the average winds from about May to August inclusive are from an easterly quarter. Experience suggests that the winds over the Greenwich meridian from 30°N to 80°N are almost entirely easterly, particularly from mid-May to mid-August. For the remainder of the year the average winds in the middle stratosphere are predominantly westerly. The variation of wind direction from one year to another and its variation from the mean pattern are larger in the 'winter' portion of the year than they are in the 'summer' season. In fact easterly winds do occur from time to time across the Greenwich meridian even in midwinter, but mostly to the south of 50°N . The average picture however is one of westerly winds in the middle stratosphere in the portion of the year from October to March. The periods of change-over from one régime to the other are short, variable in date and occur at different times of the year at different levels.

During the course of another investigation indications were found that the position of the jet stream across the Greenwich meridian may also be bi-modal in a 12-month period and this was considered interesting enough to warrant a fuller analysis.

A series of 200 mb charts, complete in the neighbourhood of the Greenwich meridian from about 30°N to 80°N , were available for the period January 1961

to July 1964. The change in contour pattern at 200 mb is fairly slow so that extraction of data from only one chart instead of two in every 24 hours caused little if any loss of information and produced a considerable saving in effort. Only 0000 GMT charts were used.

The strongest winds at the 200 mb level correspond to the main jet streams (whose cores may often be at somewhat lower heights). The strongest gradient of contour height across the Greenwich meridian on the 200 mb chart could therefore be assumed for the purpose of this investigation to show the position and direction of the main jet stream. The latitude at which the maximum gradient occurred and the direction, to the nearest 10 degrees, of the wind on the meridian were then extracted from each of the midnight charts. A maximum was not rejected because the associated jet core did not reach the value required by a strict definition of a jet stream.

The average number of occasions of wind maxima per month was obtained for each two degrees of latitude from 36°N to 69°N and, without sub-division, for latitudes north of 69°N and south of 36°N. The resultant figures are given in Table I and for latitudes 36°N to 69°N are shown graphically in Figure 1.

TABLE I—AVERAGE NUMBER OF OCCURRENCES OF WIND MAXIMA PER MONTH FOR LATITUDE BANDS STATED

Latitude degrees north	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
70 and above	7.3	7.0	2.3	2.5	1.3	2.0	1.5	0.0	3.7	2.3	2.0	4.3
68-69	2.0	0.7	0.7	0.0	0.3	0.0	0.3	0.0	0.3	2.0	0.0	1.0
66-67	1.5	1.7	0.7	0.5	0.3	0.5	0.0	0.3	2.0	2.7	1.7	4.3
64-65	1.7	1.5	0.3	0.0	0.3	0.0	0.3	0.0	1.0	2.3	0.7	0.7
62-63	1.0	1.0	1.5	0.7	0.3	0.3	0.3	0.7	1.3	1.0	0.7	1.7
60-61	1.5	1.5	2.0	0.5	0.0	1.0	1.0	0.3	2.0	2.7	1.3	1.3
58-59	0.0	1.3	1.3	0.3	0.3	0.5	2.0	0.3	1.0	0.7	0.7	0.0
56-57	2.0	1.3	1.0	1.0	0.5	2.7	1.5	2.0	2.3	4.0	2.0	1.7
54-55	0.5	0.5	0.3	1.5	0.7	2.5	2.0	2.3	1.7	1.0	0.7	1.0
52-53	0.5	0.7	1.3	1.3	1.5	1.3	3.3	4.0	2.3	1.7	1.0	1.0
50-51	2.0	1.3	1.5	1.3	5.3	4.0	4.0	5.3	3.3	3.0	1.3	3.3
48-49	0.5	0.7	0.5	0.7	2.0	1.7	1.5	3.3	2.7	0.7	0.7	1.0
46-47	1.5	1.0	1.5	1.5	3.7	1.3	2.0	3.7	1.0	2.0	2.7	0.0
44-45	1.5	1.3	1.7	1.0	3.0	1.0	1.7	2.3	0.0	1.3	2.3	1.3
42-43	2.5	1.3	3.3	2.3	1.3	0.7	3.7	3.0	1.0	1.0	3.0	1.0
40-41	0.5	0.5	1.5	1.5	1.0	1.3	3.0	1.3	2.0	1.0	1.3	1.3
38-39	0.7	0.5	0.3	1.7	1.3	1.0	2.0	0.3	1.3	0.0	0.0	0.3
36-37	2.3	2.0	3.0	1.7	1.0	1.0	2.0	0.3	1.3	0.7	0.7	1.0
35 and below	6.7	9.0	11.0	11.3	8.0	9.7	1.5	0.7	3.7	1.3	8.3	9.0

These averages are somewhat irregular in detail probably because of the small number of years for which data were to hand. Nevertheless, they show two predominant forms. In the months of May to October there is a major peak of occurrences at middle latitudes (about 50°N). For the months of November to April the highest peak is no longer in the middle latitudes; the distribution of the jet is much more uniform, with the highest peak north of 65°N or south of 45°N. On the basis of these figures one can say that the annual variation of the latitudinal displacement of the jet stream on the Greenwich meridian follows a 'two-season' pattern. It is of interest to note that this division of the average latitudinal pattern through the year is very similar to the seasonal variation of the average winds in the middle stratosphere. Of course this investigation does not establish any causal relationship between the jet stream and the stratospheric winds.

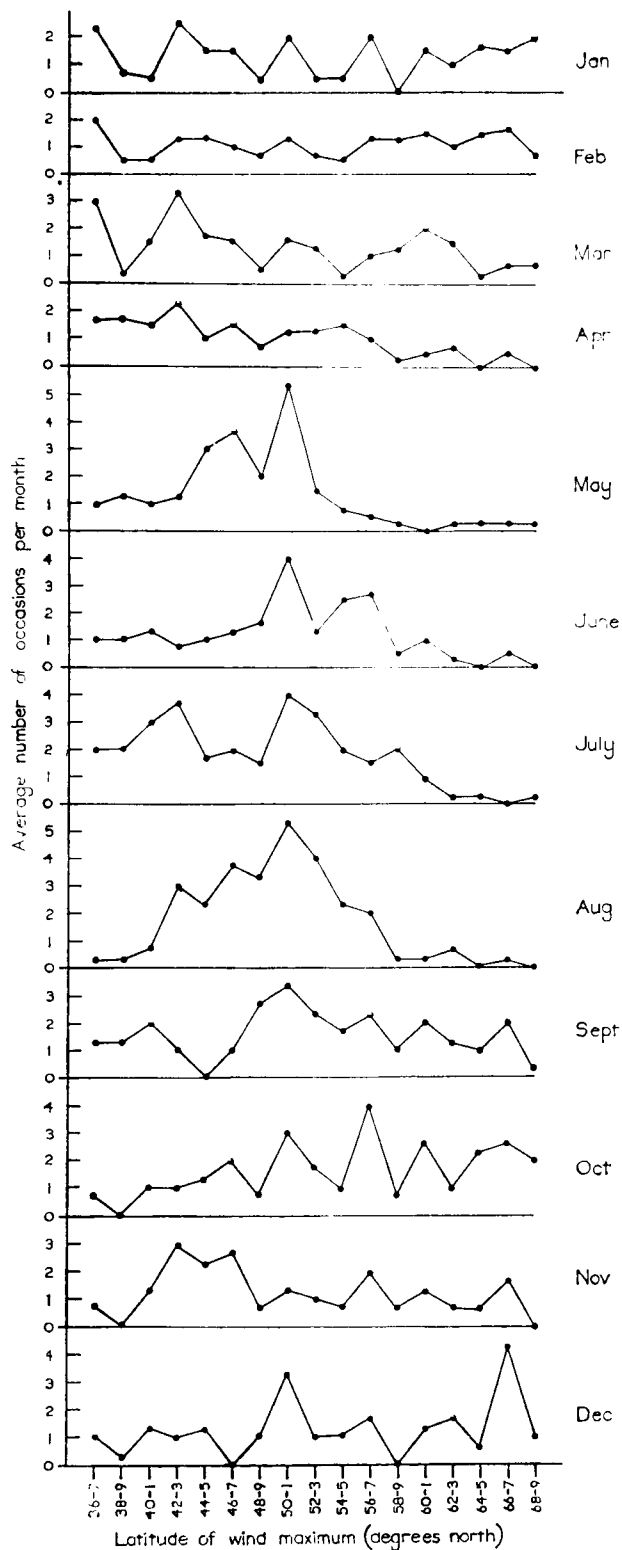


FIGURE 1—MONTHLY FREQUENCY DISTRIBUTION OF LATITUDE OF JET STREAM AT THE GREENWICH MERIDIAN

In Figure 2 are shown monthly graphs of the average distribution of the direction of the jet streams as they cross the Greenwich meridian. In these

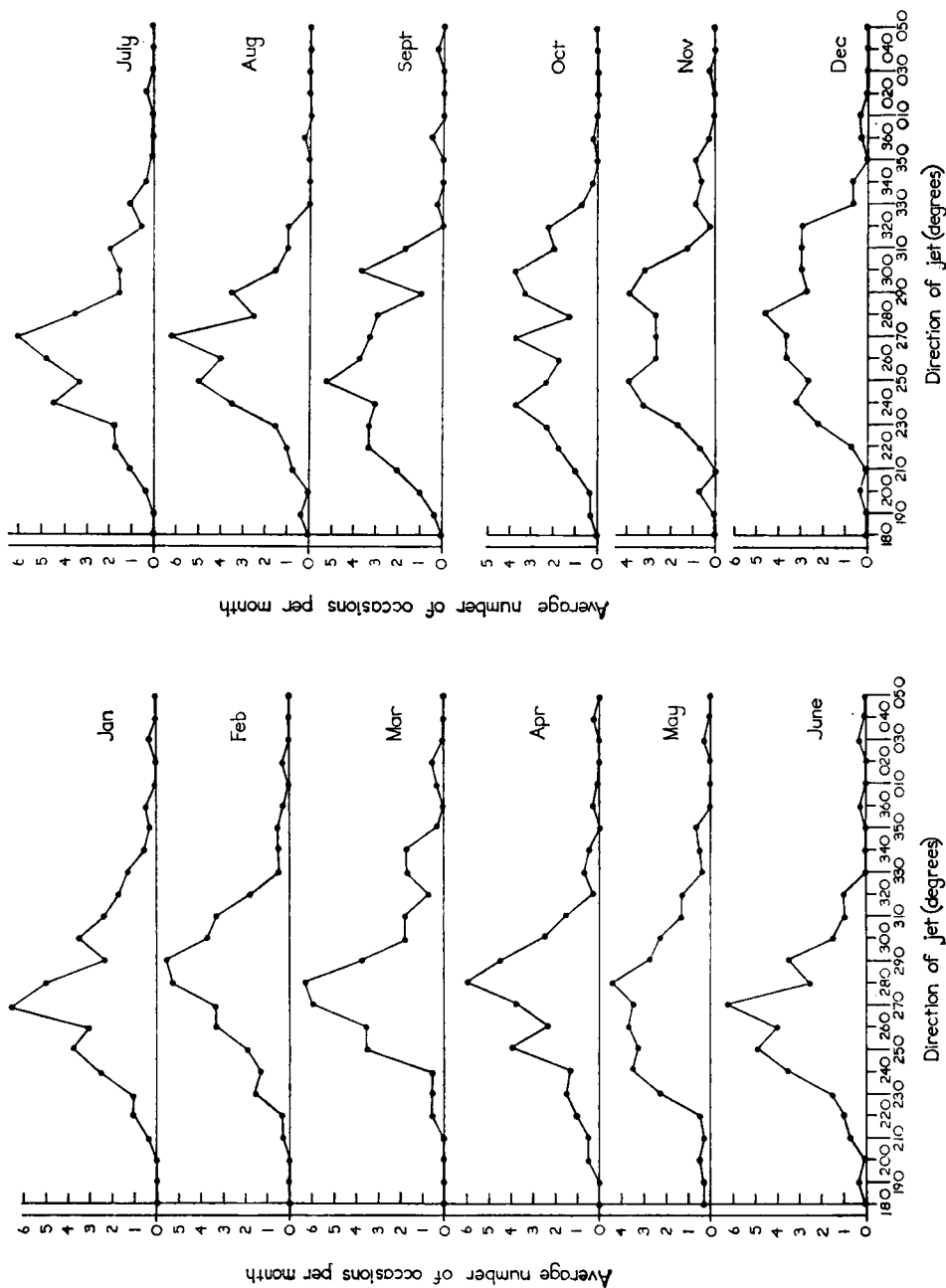


FIGURE 2—MONTHLY FREQUENCY DISTRIBUTION OF DIRECTION OF JET STREAM
AT THE GREENWICH MERIDIAN

expanding the binominal:

$$E_{\theta,v} = A \left(\frac{1}{2} \frac{v^2}{A^2} \sin^2 \theta - \frac{1}{8} \frac{v^4}{A^4} \sin^4 \theta + \dots \right) + v \cos \theta,$$

and since v/A rarely exceeds 0.4 for flights at 400 knots

$$E_{\theta,v} = v \cos \theta + \frac{v^2 \sin^2 \theta}{2A}. \quad \dots (2)$$

Inspection of equation (2) shows that the equivalent headwind depends mostly on the first term $v \cos \theta$. This is at a maximum when $\theta = 0^\circ$ and the equivalent headwind $E_{0^\circ,v}$ is v . The second term is at a maximum when $\theta = 90^\circ$ and equivalent headwind $E_{90^\circ,v} = v^2/2A$. The ratio of the two maxima is

$$\frac{E_{0^\circ,v} \text{ (headwind)}}{E_{90^\circ,v} \text{ (beamwind)}} = \frac{2A}{v},$$

and since v rarely exceeds 160 knots at 300 millibars and $A = 400$ knots for most subsonic jet aircraft, the ratio is unlikely to exceed 5 : 1. Inspection

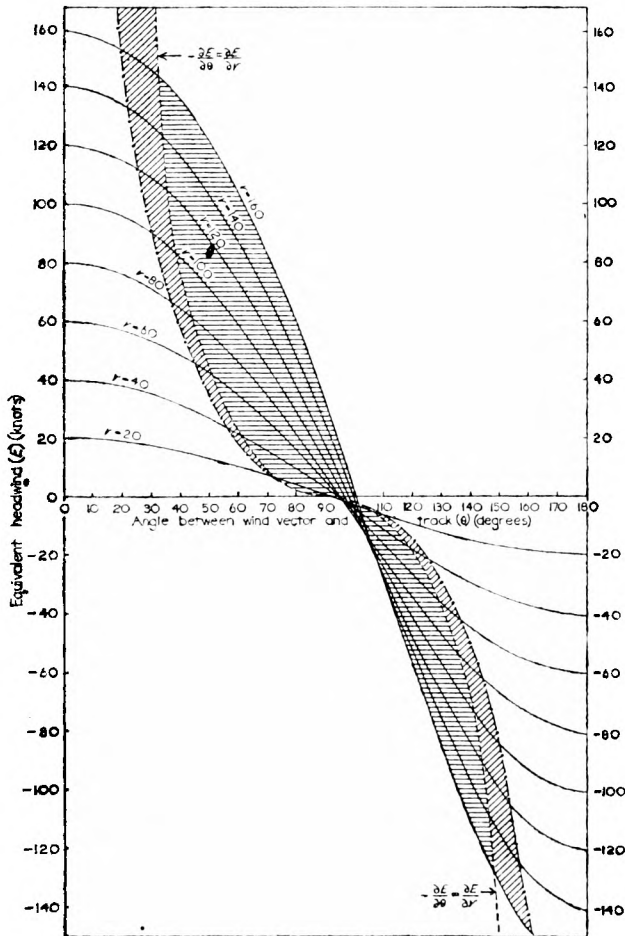


FIGURE 2—EQUIVALENT HEADWIND, E , AGAINST θ FOR SEVERAL VALUES OF v

Horizontal shading — area where errors in θ (degrees) produce greater errors in E than errors of similar magnitude in v (knots).

Diagonal shading plus horizontal shading — area where errors in θ (degrees) produce greater errors in time lost than errors of similar magnitude in v (knots).

True airspeed, $A = 400$ knots.

of the term $v \cos \theta$ shows that, especially for large values of v , there will be a wide range of values of θ for which the equivalent headwind is very sensitive to errors in θ .

Relative effects of error in forecasting wind speed and direction.—

Current forecasting techniques lead the upper-wind forecaster to approach the problem in two steps, firstly a forecast of wind direction in terms of the contour height pattern, and secondly a forecast of wind speed in terms of the contour spacing or the isotach pattern. Zone wind forecasts are usually given to the nearest 10° and 10 knots and the forecaster thinks of the accuracy of his forecast in these terms, rather than in terms of equivalent headwind. Although the forecaster may know the tracks to be flown it is often difficult to visualize the equivalent headwind from the forecast wind. It is particularly difficult to see the relative effects of forecast errors in the wind speed and direction because the relative contributions to equivalent headwind vary with the angle between the wind vector and the track. This is readily seen from Figure 2 in which the equivalent headwind E is plotted against θ for several values of v with an assumed airspeed of 400 knots. The family of curves are intersected by a dotted curve representing the equality $-\partial E/\partial \theta = \partial E/\partial v$, where θ is in degrees and v in knots and it is apparent that for winds exceeding about 60 knots there are wide ranges of θ in which the equivalent headwind is more sensitive to errors in wind direction than to errors in wind speed.

For each value of v there is a maximum of $\partial E/\partial \theta$, this being equal to 2.8 knots per degree when v is 160 knots. These maximum values occur with θ in the range $90-110$ degrees.

Time error resulting from forecast wind direction error.—The full effect on a flight of forecast errors in θ and v depends not only on the error in equivalent headwind but also on the time for which the error is experienced. Suppose a flight is crossing a strong wind belt w miles wide at an angle θ to the track (Figure 3). The distance along the track occupied by the wind belt is $FG = w \operatorname{cosec} \theta$, the ground speed while crossing it is $(A - E_{\theta, v})$ knots and the time taken to cross it is $(w \operatorname{cosec} \theta)/(A - E_{\theta, v})$. The time taken to fly

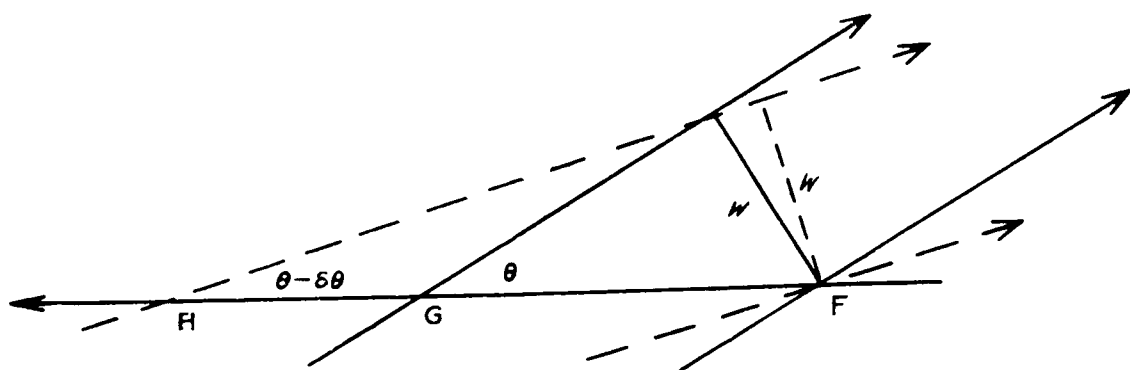


FIGURE 3—DERIVATION OF TIME ERRORS RESULTING FROM FORECAST WIND ERRORS

- w = width of jet stream with forecast and experienced wind speed v ,
- θ = angle of jet stream to track,
- $\theta - \delta \theta$ = forecast angle of jet stream to track,
- FG = $w \operatorname{cosec} \theta$ = actual distance along track occupied by jet stream,
- FH = $w \operatorname{cosec}(\theta - \delta \theta)$ = forecast distance along track occupied by jet stream.

the same distance in calm conditions would be $(w \operatorname{cosec} \theta)/A$ and the time lost due to wind would be

$$(w \operatorname{cosec} \theta) \left(\frac{1}{A - E_{\theta, v}} - \frac{1}{A} \right) \text{ which equals } \frac{E_{\theta, v} w \operatorname{cosec} \theta}{A (A - E_{\theta, v})} \dots (3)$$

Using expression (3) it can be shown that, for a wide range of θ , the total effect on a flight of a directional error $\delta\theta$ (degrees) greatly exceeds the effect of a speed error δv (knots) of the same magnitude and the ratio of the errors in terms of time lost is materially greater than the ratio of the two equivalent headwinds for θ between 20 and 50°.

In considering the full effect of an error $\delta\theta$ in terms of time lost it is necessary to examine that part of the track on which the strong wind or jet stream is forecast to occur and to compare the forecast time lost with the actual time lost over the same distance.

Using expression (3), the forecast time lost along FH in Figure 3 is

$$\frac{E_{\theta - \delta\theta}}{A (A - E_{\theta - \delta\theta})} \times w \operatorname{cosec} (\theta - \delta\theta) \dots (4)$$

(as it is here assumed that there is no forecast error in the wind speed v , the suffix v in $E_{(\theta - \delta\theta), v}$ is omitted for brevity).

To arrive at the actual time lost along FH, it is necessary to make some assumptions about that part of the track GH which was not affected by the jet stream. The wind speed must be less than the jet speed v because GH lies outside the jet stream and, unless the angle of the wind flow to the track is much smaller than the angle θ in the jet stream, it is reasonable to assume that the equivalent headwind along GH cannot exceed the equivalent headwind along FG. Therefore the actual time lost along FH cannot exceed the value obtained on the assumption that a jet stream (wider than w) with speed v and at angle θ to the track covered the entire distance FH. From expression (3) and the relation $FH = w \operatorname{cosec} (\theta - \delta\theta)$, the actual time lost along FH is

$$\leq \frac{E_{\theta} w \operatorname{cosec} (\theta - \delta\theta)}{A (A - E_{\theta})} \dots (5)$$

An estimate of the minimum forecast time error is obtained by subtracting expression (5) from expression (4). For a small increment $\delta\theta$, $(A - E_{\theta}) \simeq (A - E_{\theta - \delta\theta})$: therefore the forecast time error is

$$\geq \frac{w \operatorname{cosec} (\theta - \delta\theta)}{A (A - E_{\theta - \delta\theta})} \times (E_{\theta - \delta\theta} - E_{\theta}) \dots (6)$$

Time error resulting from forecast wind speed error.— If θ is now forecast correctly but an error $+\delta v$ knots (equal in magnitude to $-\delta\theta$ in the previous section) is made in forecasting v , then the jet stream occupies the same distance FG (in Figure 3) on both forecast and actual charts and, using expression (3), the forecast time lost along FG is

$$\frac{E_{v + \delta v}}{A (A - E_{v + \delta v})} w \operatorname{cosec} \theta, \dots (7)$$

the actual time lost along FG is

$$\frac{E_v}{A (A - E_v)} w \operatorname{cosec} \theta, \dots (8)$$

and the forecast time error along FG is obtained by subtracting expression (8) from expression (7).

If it is now assumed that the forecast error δv in zone FG does not produce an error in the adjoining zone GH, then the forecast error due to δv along FG will apply to the longer sector FH, i.e. the forecast time error along FH due to δv is

$$\frac{w \operatorname{cosec} \theta}{A(A - E_{v+\delta v})} E_{v+\delta v} - \frac{w \operatorname{cosec} \theta}{A(A - E_v)} E_v .$$

And, since for a small increment δv , $(A - E_{v+\delta v}) \simeq (A - E_v)$, the forecast time error along FH is

$$\simeq \frac{w \operatorname{cosec} \theta}{A(A - E_v)} \times (E_v + \delta v - E_v) . \quad \dots (9)$$

Relative time errors due to forecast errors in wind direction and wind speed.—From expressions (6) and (9), the minimum value of the ratio of the forecast time error along FH (in Figure 3) due to $-\delta\theta$ (v correctly forecast) to the forecast time error along FH due to an error δv knots of equal magnitude (θ correctly forecast) is given by

$$\frac{\text{Time error due to } \delta\theta}{\text{Time error due to } \delta v} \geq \frac{[w \operatorname{cosec}(\theta - \delta\theta)]/A(A - E_\theta)}{(w \operatorname{cosec} \theta)/A(A - E_v)} \times \frac{(E_\theta - \delta\theta - E_\theta)}{(E_v + \delta v - E_v)} ,$$

but E_θ and E_v are identical, and the expression reduces to

$$\geq \frac{\operatorname{cosec}(\theta - \delta\theta)}{\operatorname{cosec} \theta} \times \frac{(E_\theta - \delta\theta - E_v)}{(E_v + \delta v - E_v)} .$$

Therefore the ratio of the time errors due to $\delta\theta$ and δv is greater than the ratio of the corresponding errors in the equivalent headwinds by a factor of not less than $\operatorname{cosec}(\theta - \delta\theta)/\operatorname{cosec} \theta$. Table I shows this ratio for various values of θ when $\delta\theta = 10^\circ$ and it is apparent that the full effect of errors in θ on the time of flight must be considerably greater than the effect on equivalent headwind and must extend over wider ranges of θ than those contained within the horizontally-shaded area in Figure 2. The probable minimum extension of the area when errors are considered in terms of time lost because of errors in θ of 10° is shaded diagonally.

TABLE I—RATIO $\operatorname{COSEC}(\theta - 10^\circ)/\operatorname{COSEC} \theta$ FOR VARIOUS VALUES OF θ

θ degrees	$\operatorname{Cosec} \theta$	$\operatorname{Cosec}(\theta - 10^\circ)/\operatorname{cosec} \theta$
90	1.0000	1.02
80	1.0154	1.05
70	1.0642	1.09
60	1.1547	1.13
50	1.3045	1.19
40	1.5557	1.28
30	2.0000	1.46
20	2.924	1.97
10	5.759	∞

Some general considerations.—In addition to the effects already discussed there are also important differences in the way errors are correlated along a route, depending on the angle between the aircraft's track and the general wind direction. Consider first a broad straight flow with shear. For a route making a small angle to the general direction of flow, the equivalent headwind depends mainly on the forecast wind speed and will be very sensitive to the positioning of the strongest flow with respect to the track flown. Forecast errors will tend to be positively correlated along the track and the total

error in terms of equivalent headwind is unlikely to decrease rapidly with increasing route length. In contrast, for a route normal to the flow, errors tend to be negatively correlated and the equivalent headwind errors should decrease rapidly with increasing route length. Also, when the wind is mainly beamwind the equivalent headwind is less by a factor of at least five than for a similar wind directed along the track (see page 342).

Now consider a wave pattern superimposed on the broad flow. Equivalent headwinds for a track along the general flow must decrease as the amplitude of the wave pattern increases and it has been shown that the forecast wind direction is more important than the forecast wind speed unless the wind flow is almost entirely a headwind. For a route directed along the general flow the actual positions of troughs and ridges in the wave pattern are of little importance if the route is long compared with the wavelength. For a track crossing the flow the angle θ between the track and the wind direction depends critically on the position of the pattern. If positive and negative errors in forecasting the wave pattern are equally likely then, for tracks across the mean flow, the mean error for a long series of equivalent headwind forecasts should tend towards zero but the standard deviation will be large. Any tendency to underestimate the amplitude of the wave pattern will underestimate the equivalent headwind and restrict the gross errors.

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SYMPOSIUM ON METEOROLOGICAL DATA-PROCESSING, BRUSSELS, 1965

A symposium on meteorological data-processing was held at the Royal Meteorological Institute, Brussels, from 2 to 5 July under the joint auspices of the World Meteorological Organization (WMO) and the International Union of Geodesy and Geophysics. The meetings had been planned to provide a forum for the discussion of the problems of providing the research meteorologist with the data which he requires for the study of the large- and medium-scale systems in the atmosphere, and to consider the steps which might be taken to ensure that the maximum value for research is obtained from the very large number of observations which are made each day.

It was clear from the discussion that these matters give particular concern at the present time because of the rapid increase in the available data, also because of the rapid changes in the technology for data-processing on electronic computers and for data storage, and because of the reorganization of the handling of synoptic data to be expected with the gradual implementation of World Weather Watch.

The programme included several speakers who aimed to outline the requirement of the research scientist for meteorological data. Professor P. A. Sheppard stressed the need to ensure that research students are aware of what data are available and relevant to their problem and Mr. J. S. Sawyer emphasized the continuing need for published series of synoptic charts among which the research scientist can browse and thus acquire the familiarity with the atmosphere needed to formulate his problems; it is difficult, if not impossible, to visualize the problems while data remain in digital form.

Other speakers described their experiences in processing meteorological data on electronic computers. These ranged from small computers in Austria and India to large installations in the U.S.A., and covered a wide range of purposes from strict climatology to numerical weather prediction. Although all reported various difficulties, particularly in respect of lack of uniformity of format of the data, it was clear that all the speakers expected that the electronic computer would in the future have a rapidly increasing importance in meteorological data-processing throughout the world.

Much discussion centred around the desirability of the very large random-access computer stores which are now becoming technically feasible. The meeting was told that stores of up to 10^{12} bits (binary digits) could now be built and that this is several times greater than the data content of the climatological records of the U.S. Weather Bureau at Asheville. Speaking from experience at Asheville, Mr. J. F. Bosen emphasized the need for permanence in the records such as is provided by some photographic methods of recording now available. He said that it was difficult to eliminate the risk of erasure of records on magnetic tape.

At a final discussion some recommendations were drafted which drew the attention of WMO to the special problems of providing data for research, and stressing in particular the need for world data centres with adequate facilities.

The success of the symposium owes much to the excellent facilities provided by the Royal Meteorological Institute of Belgium.

J. S. SAWYER

REVIEWS

Cloud structure and distributions over the tropical Pacific Ocean by J. S. Malkus and H. Riehl. $8\frac{3}{4}$ in \times $10\frac{1}{4}$ in, pp. ix + 227, *illus.*, University of California Press, Berkeley and Los Angeles (distributed by Cambridge University Press, Bentley House, Euston Road, London NW1), 1964. Price £3.

This book contains a detailed record of an investigation of tropical oceanic clouds by two world authorities on the subject. The main material used was a time-lapse colour film for which frames were exposed at one-second intervals from an aircraft flying at about 8000 feet. The flights were made in July and August 1957 and covered 15,000 miles, mainly between latitudes 10 and 20 degrees north on routes between Honolulu and Guam. The whole gamut of tropical oceanic activity was experienced, from almost cloudless conditions, through undisturbed trade-wind cumulus régimes, minor disturbances, easterly waves, and small cyclonic circulations to a full-blown typhoon.

The cloud pictures on each flight were related to the three-dimensional structure of the atmosphere by various analyses of the routine synoptic surface and upper air observations, the utmost information being extracted from the all too sparse network. A good portion of the book is taken up with charts of surface isobars, low-level wind flow, shear winds in lower and upper troposphere, precipitable water, tephigrams, wind profiles, cloud and humidity cross-sections, together with tables of observational data and descriptive material. All this is a model of clear and careful analysis.

An important step in the method of analysis was to codify the appearance of the sky as shown in the cloud photographs. The authors found that 17 code

figures were adequate, 5 for undisturbed trade-wind skies, 5 for weak disturbances and 7 for strong disturbances. Good agreement was obtained between the code figures allotted by different observers. To the reviewer this 'Tropical Whole Sky' code seems one of the most valuable features of the book. Several hundred cloud photographs taken near Christmas Island were examined by him and the impression was gained that with a little practice it would be possible to allot code figures satisfactorily and consistently. Photographs typical of each code figure are included in an appendix to the book, together with definitions of each type of sky. Unfortunately it is here that one of the few criticisms of an otherwise excellently produced book must be made. The quality of the reproduction of the cloud photographs leaves something to be desired, partly, no doubt, because of the change from colour to black and white, and to the fact that non-glossy paper is used. In the appendix lack of clarity is increased by the small size (less than 3 by 2 inches) of each picture. Elsewhere in the book selected photographs occupying a whole page are much more impressive. The importance of the 'Tropical Whole Sky' code is such that it could usefully be published as a separate document with large pictures, and would then greatly facilitate cloud reporting from aircraft over the tropical oceans.

The authors do not, however, stop at description; they seek to explain and elucidate what they observed. The sections dealing with the fairly common organization of cumulus clouds into lanes are particularly useful. Adjacent frames from the film could be used as stereo pairs and a measuring technique was devised to provide estimates of the position and size of individual clouds. A great many of these measurements were made and detailed charts were drawn of sections of the route where lane structure was well marked. Much the commonest mode of organization was into lines nearly parallel to the low-level streamlines. In the absence of other data, therefore, observations of cloud lanes could provide useful information on surface wind flow, though the correspondence is not exact. Less frequently observed was an organization of clouds into lines across the low-level winds. A factor thought to favour this mode was the development of the cumuli through sufficient depth to penetrate an upper layer of strong shear in the wind, the cross lines of cloud then being roughly parallel to the shear vector. On occasion both forms of organization appeared simultaneously.

Other plausible, but more speculative, relations are discussed. It was observed that almost all the rain was associated with major disturbances. Often differences between wet and dry situations are small in the conditions near the surface and the authors explain the development of large convective storms by wind flows in the upper troposphere which lead to increased anticyclonic vorticity and divergence, with compensating convergence at low levels. The need for much more numerous wind observations to elucidate such relations is stressed.

The book is one which no meteorologist dealing with tropical oceanic weather can afford to ignore. To the newcomer to the field it gives an excellent insight into how clouds develop and behave over tropical oceans and the investigator will find much material to stimulate him.

M. H. FREEMAN

Read well and remember by Owen Webster. 8 in \times 5 $\frac{1}{4}$ in, pp. 280, Hutchinson & Co., 178-202 Great Portland Street, London W1, 1965. Price: 20s.

This is a book for all readers who wish to use their time profitably when they have to learn from the printed word. Most students and research workers have

taught themselves a good deal about how to remember what they read using such rules as: read material more than once; write summaries; relate new knowledge to old; use mnemonics; and so on. They may even have learnt a few tricks of fast reading and skimming. But the subject of reading efficiency is not widely taught and many readers will benefit from learning the principles and putting them into practice under the author's guidance. No unusual standard of knowledge or of memory is required and the principles can be applied in any subject field or to any type of writing.

Mr. Webster has studied his subject as a student and as a lecturer, and has used his experience to communicate his ideas to readers and obtain their co-operation in carrying out his instructions. The result is a well-planned 'teach yourself' book; each chapter contains carefully chosen passages for reading, and exercises designed to stimulate as well as guide. The reader can measure his own speed of reading and his power of comprehending and remembering; and he may be impressed by his own improvement or by some of the author's forecasts of the results of exercises. Techniques of reading and studying are explained but the reader is also taught to read with a purpose and to look for the underlying philosophy of what he is reading. Besides being critical the reader must be actively involved in finding answers to his questions. Another feature of the book is the wide range of interests shown in the examples and reading lists (no doubt stemming from the author's experience in the world of books and journalism), and the encouragement given to readers to extend their reading into areas outside their own special activities.

Several books have been published in Britain recently to help writers to improve their standard. This book meets an obvious requirement in that it helps readers but it is also a useful book for writers interested in the best way of communicating ideas to readers.

W.S.G.

The amateur weather forecaster by E. S. Gates. 7½ in × 5½ in, pp. 93, *illus.*, George G. Harrap & Co. Ltd., 182 High Holborn, London WC1, 1965. Price: 6s.

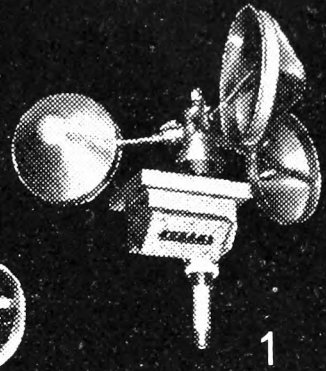
At first glance this is an attractive publication with good type and clearly drawn diagrams. But both text and diagrams contain many imprecisions and errors of fact. For instance, on page 23 pressure gradient is defined and followed by the misleading statement "thus it indicates the velocity and general direction of air movements." In several respects figures 27, 28 and 30 give a false picture of a depression. There is even a lot of misinformation in Appendix II about the meaning of terms used in weather forecasts for the public.

The reviewer cannot recommend this book to any amateur weather forecaster.

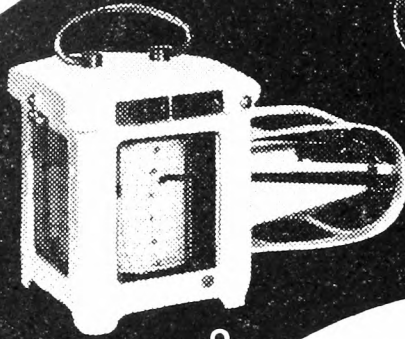
R. J. OGDEN

CORRIGENDA

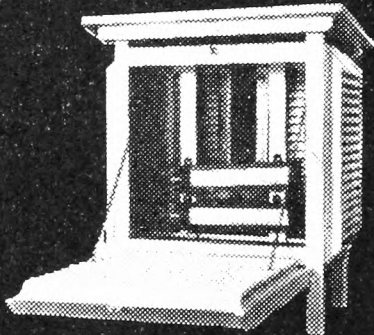
Meteorological Magazine, June 1965, p. 173, 'The yearly distribution of rainfall intensities', two lines below equation (1): for "i the average rate" read "ī the average rate"; p. 177, to Figure 3 add "the straight line is given by equation (1)"; p. 179, Figure 4, delete "the straight line is given by equation (1)".



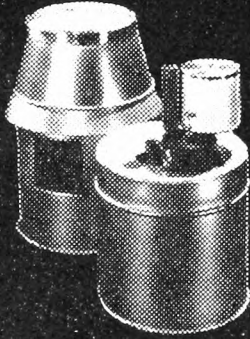
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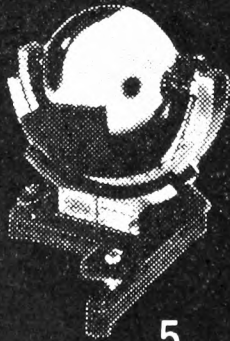
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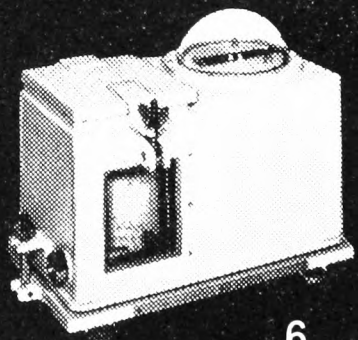
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A PARAMETER FOR THE OBJECTIVE LOCATION OF FRONTAL ZONES

By T. H. KIRK

In their interesting note¹ Messrs Carlson, Galloway and Haering call attention to a paper² dealing with the objective location of frontal zones. The present note is concerned with the same problem ; given a thermal distribution at any isobaric level aloft, what is the appropriate parameter to use for the location or delineation of a frontal zone ?

Suppose the element α is chosen for use, i.e. suppose that isopleths of α are depicted on a chosen isobaric surface. These isopleths define the distribution of the gradient of α which will vary from place to place, not only in magnitude but also in direction. If it is desired to depict the zones where the largest changes in the gradient of α occur then there appear to be alternative procedures.

The first is to ignore the changes of direction of $-\nabla\alpha$ and to consider the magnitude of this vector as being of sole relevance to the problem. This magnitude may be written as $|\nabla\alpha|$ and the relevant parameter for consideration would then be $(\nabla|\nabla\alpha|) \cdot \bar{a}$ where \bar{a} is a unit vector in the direction $\nabla\alpha$.

The second procedure is that of taking account of changes in the direction of the gradient of α because there can be no *a priori* reason for supposing that these are not dynamically of relevance. The question then arises : what is the appropriate parameter to use ? In deciding this, the following considerations are of assistance :

- (i) Whatever parameter is chosen, its use should give the same answer for straight isopleths as the parameter $(\nabla|\nabla\alpha|) \cdot a$ so as to be consistent with normal practice and ideas.
- (ii) The parameter should have obvious physical significance.
- (iii) The parameter should be of simple mathematical form.

One might expect that the divergence of the gradient of α would be an appropriate measure. This quantity can be written $\text{Div}(-\nabla\alpha) = -\nabla^2\alpha$, where ∇^2 is the Laplacian operator. The criteria (ii) and (iii), above, are obviously satisfied.

Also

$$\begin{aligned}\text{Div } \nabla \alpha &= \text{Div } (|\nabla \alpha| \bar{a}) \\ &= (\nabla |\nabla \alpha|) \cdot \bar{a} + |\nabla \alpha| \text{Div } \bar{a}.\end{aligned}$$

For straight isopleths of α , $\text{Div } \bar{a} = 0$ and therefore criterion (i) is satisfied. The theoretical implications of this new approach will be discussed elsewhere.

Figure 1 shows an 850 mb chart for N. America for 0000 GMT, 4 February 1963 on which the isotherms have been drawn. Figure 2 shows the distribution of $\nabla^2 \alpha$ worked by hand using the normal simple grid technique.

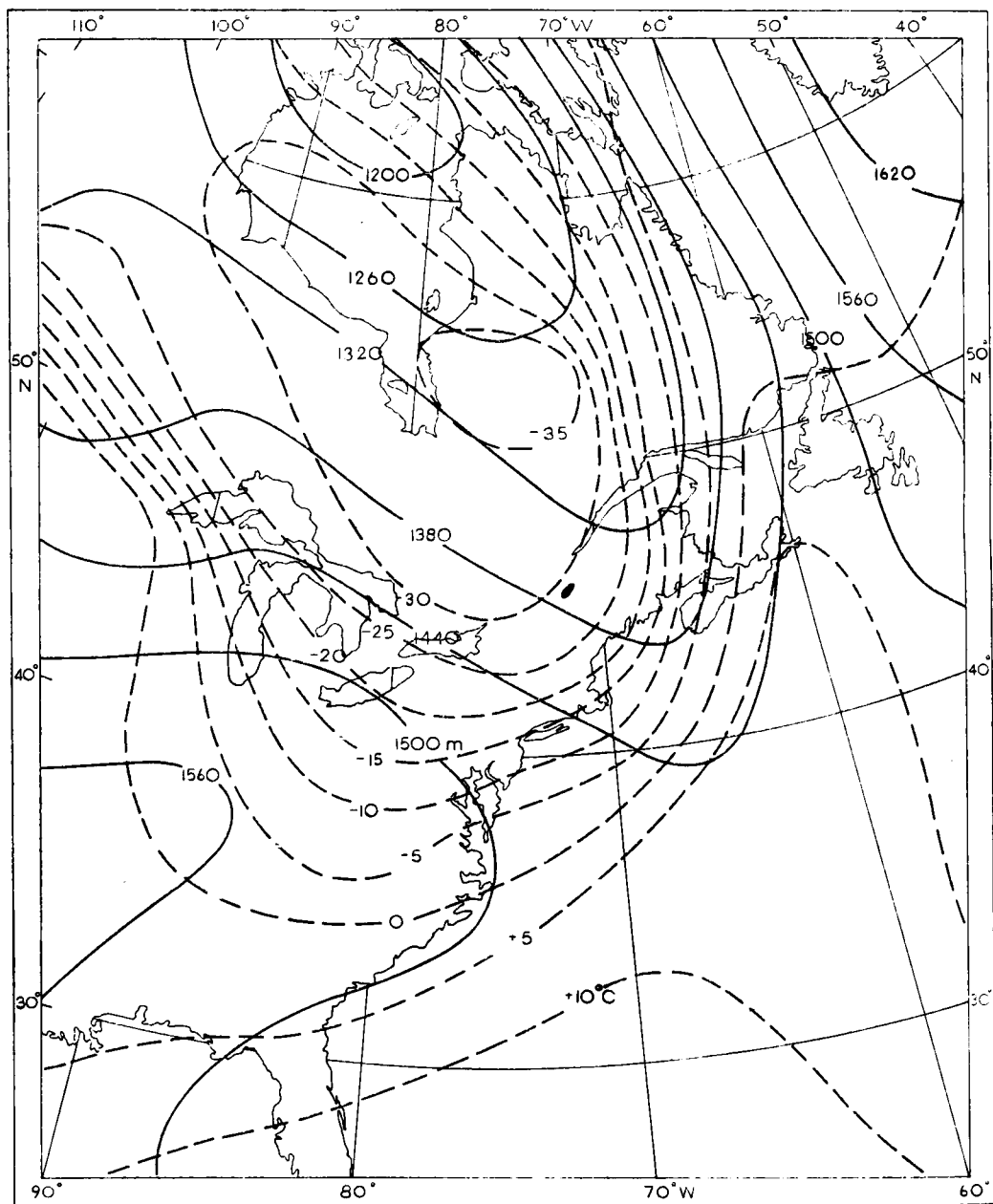


FIGURE 1—850 MB CHART FOR 0000 GMT, 4 FEBRUARY 1963

—— contours

- - - isotherms

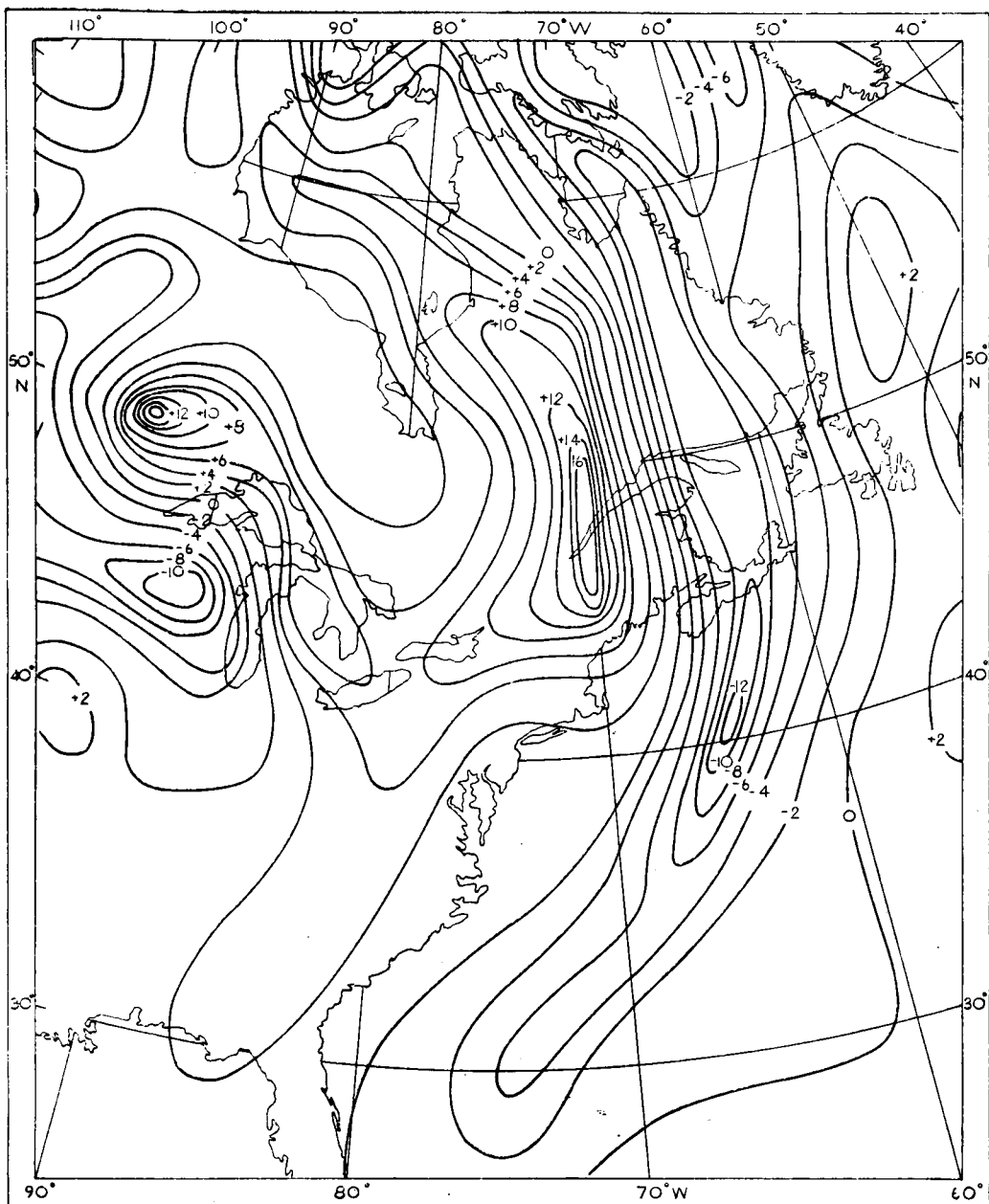


FIGURE 2—DISTRIBUTION OF $\nabla^2\alpha$ BASED ON A SQUARE GRID OF 300 NAUTICAL MILES FOR 0000 GMT, 4 FEBRUARY 1963

The edges of the frontal zone are marked by the critical values of $\nabla^2\alpha$ on either side, the frontal zone itself consisting of a strong gradient of the quantity $\nabla^2\alpha$.

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2. RENARD, R. J. and CLARKE, L. C.; Experiments in numerical objective frontal analysis. *Mon. Weath. Rev., Washington D.C.*, **93**, 1965, p.547.

VERY LOW CLOUD AT LONDON (HEATHROW) AIRPORT DURING THE WINTER HALF-YEAR

By J. E. ATKINS

Summary.—For London (Heathrow) Airport occurrences of very low cloud during the months of October to March have been analysed in relation to geostrophic wind and time of day. Features are shown which appear to have significance for the forecaster but it is difficult to distinguish effects that are purely local from those due to general synoptic tendencies. Some features vary considerably from one part of the winter half-year to another.

Introduction.—In describing the local weather characteristics of an aerodrome, a forecaster will often say that the likelihood of a very low cloud base is considerable with winds from one direction but slight or negligible with winds from another direction. This sort of statement may be qualified by mention of wind speed, e.g. with winds from a certain direction the cloud base is unlikely to be very low so long as the wind is stronger than a given value. Such guidance is valuable to any forecaster who has little experience of forecasting for that aerodrome. It is not altogether satisfactory, however, that guidance should be entirely dependent on personal experience and judgement. Consequently ways have been considered of presenting statistics of the height of cloud base according to wind.

Statistics could be compiled to relate cloud height with either surface or geostrophic wind. For convenience in data processing the surface wind is a particularly suitable parameter: for many places observations are recorded on punched cards, each card containing the simultaneous values of cloud height and surface wind. From the forecaster's point of view, however, there is some advantage in using geostrophic wind rather than surface wind as a parameter because the pressure distribution is forecast before consideration is given to the individual elements of weather to be expected. The routine forecasting of pressure distribution will increasingly be carried out by electronic computer so that geostrophic wind may to a large extent be forecast objectively in future.

Though the geostrophic wind is frequently determined from the synoptic chart during the course of forecasting, values have rarely been recorded systematically so that use of the geostrophic wind as a parameter in statistical investigations has been difficult. Now, however, evaluations can be made by electronic computer using a method devised by Freeman.¹ Geostrophic winds have been calculated by this method for Heathrow for each synoptic hour, i.e. three-hourly during the 13 winter half-years from October 1949 to March 1962. The analysis given here was made possible by the existence of these data.

Though the main object of the analysis has been to relate cloud height with geostrophic wind, the frequency of very low cloud at each synoptic hour of the different months has also been given since these results were readily available and appeared to be of some interest.

Cloud ceiling.—For convenience the cloud height analysed in this article is referred to as the ceiling and is the height above the aerodrome of the base of the lowest cloud of five oktas or more in amount, or — if the sky was obscured — the vertical visibility. If the sky was obscured but no vertical visibility recorded, the ceiling was taken as zero.

This definition may blur the distinction between very low stratus, beneath which visibility is not poor enough to prevent the landing of aircraft, and fog with a vertical visibility of one or two hundred feet. Nevertheless if the ceiling is very low conditions must at least be marginal for the landing of aircraft.

Another objection might be raised against the use of cloud ceiling because the forecaster tends to regard as separate phenomena :

- (a) fog (or lifted fog), and
- (b) cloud on or near the surface.

However, the formation of both is most commonly due to air being in contact with a cold surface — whether fog or stratus forms depends largely on wind speed. Also when compiling statistics the observation alone does not permit distinction between fog (with sky obscured) and cloud on the surface, or between lifted fog and stratus.

Presentation of results.—At first, frequencies of ceilings were tabulated separately for the two-month periods October/November, December/January and February/March, according to the following ranges of geostrophic wind :

Less than 7 knots (without regard to direction)	
7-14 knots	} For wind-direction sectors
15-24 knots	
25-39 knots	
40 knots or more	
	350-010°, 020-040°, 050-070°, etc.

Although nearly 19,000 values of geostrophic wind were available for analysis, the number of observations in many of the classes was small. Consequently various combinations of classes have been made as seemed best suited to illustrate different aspects. The results are presented in Figures 1-3 and Table I ; where a range of geostrophic wind is specified the number of occasions of wind within that range is given in brackets so that too much reliance is not placed on any result based on few observations. For simplicity only results for ceilings below 300 feet and below 600 feet have been presented though results are available for other ranges of cloud ceiling up to 1000 feet above the aerodrome.

The statistics are designed to answer the question : “For a given forecast geostrophic wind (e.g. from a prognostic chart) how likely is the cloud ceiling to be very low ?” This, of course, is an over-simplification of the forecaster’s reasoning since he considers not only the expected geostrophic wind but other synoptic information, attaching particular importance to details of temperature and humidity in the lowest layers of the atmosphere. Nevertheless it is of some value to consider the general effects associated with wind. Even with synoptic features which tend to give very low cloud (warm sectors, active fronts, airflow off the North Sea), variation of cloud height from aerodrome to aerodrome is usual and frequently great enough to be of operational importance — the locally important factors are often the shelter or exposure associated with winds from a particular direction.

Some results for the winter half-year as a whole.—The separate effects of wind direction and wind speed during the winter half-year are shown in Figure 1.

Figure 1(a) shows that very low ceilings are less likely with geostrophic winds from about north-west than from other directions ; for example with winds from the sector 290°–010° the probability of a ceiling below 600 feet is less than a quarter of that with winds from the sector 080°–130°. To a large extent this must be a reflection of the synoptic tendency for north-westerly winds to be associated with polar maritime air, i.e. air which is unstable when it reaches the British Isles and consequently is unsuitable for the formation of fog or stratus. However the improbability of north-westerly winds being accompanied by fog or stratus may be partly accounted for by the local topography and this aspect will be discussed later.

From Figure 1(b) it is seen that the likelihood of very low cloud or fog deep enough to obscure the sky decreases sharply as the speed of the geostrophic wind increases. This tendency is, of course, to be expected at an inland aerodrome on rather flat terrain and at only a small height above sea level (80 feet).

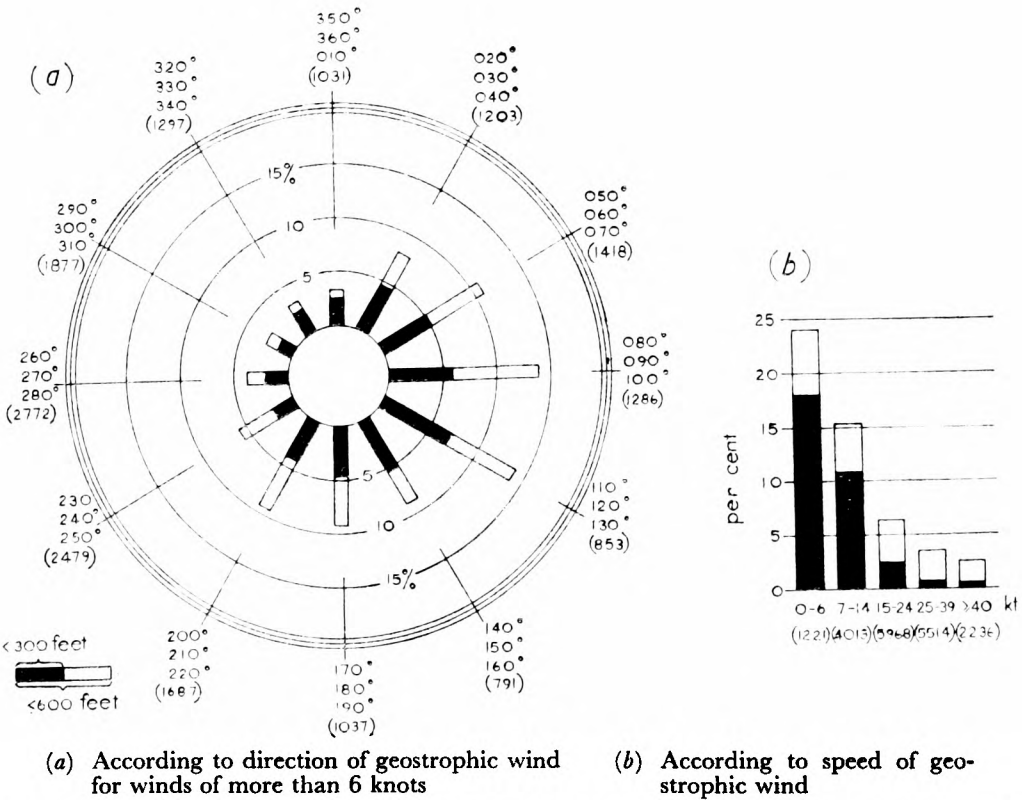


FIGURE 1—PERCENTAGE PROBABILITIES OF CLOUD CEILING BELOW 300 FEET AND BELOW 600 FEET DURING THE WINTER HALF-YEAR AT HEATHROW

A forecaster might expect the statistics to show that with geostrophic winds stronger than a critical value there is little likelihood of a very low ceiling. The ranges of wind speed used in this analysis were too broad to suggest any well-defined value, but it is notable that out of 7750 occasions when the geostrophic wind was 25 knots or stronger, the ceiling was below 300 feet on only 39 occasions (0.5 per cent) which is few enough to make examination of the individual cases practicable. Certain common features of weather and synoptic situation can be noted in these cases as follows :

- (i) On 17 of the occasions advection was occurring of air which was much warmer and moister than that being displaced. Often the low ceiling occurred near a front between tropical maritime air and either polar continental air or air of polar origin which had become stagnant and been cooled by prolonged radiation. Usually temperatures overnight had recently been very low, the grass minimum temperature recorded at 0900 GMT on the day in question or the previous day being well below 0°C—in one case as low as -16°C .
- (ii) On 14 of the occasions snow was falling.
- (iii) On 4 of the occasions a low ceiling had persisted for a time after the tightening of the pressure gradient. Three hours before the occasions the ceiling had been below 300 feet with geostrophic winds of less than 25 knots. Three hours after the occasions either the ceiling had lifted or the geostrophic wind had decreased to become less than 25 knots again.

Thus the large majority of cases with geostrophic wind of more than 25 knots and ceiling below 300 feet occur with snow falling or with warm moist air being advected over cold ground, i.e. in special circumstances when the forecaster would not expect strong winds to give the normal immunity from very low cloud.

Detailed results for different parts of the winter half-year.—In Figure 2 results are shown for two-month periods and for two ranges of wind speed. The comparative freedom from low ceilings when geostrophic winds are from the north-west is notable during each of the two-month periods and with both ranges of geostrophic wind speed.

From the upper diagrams of Figure 2 it appears that with the stronger winds ceilings below 600 feet are, on the whole, more likely with winds from the south-east quarter than from other directions ; the infrequency of ceilings below 300 feet needs no further comment.

From the lower diagrams it is seen that for geostrophic winds of 7–24 knots there is considerable variation from one part of the winter half-year to another in the wind directions which give particular risk of low ceilings. Notable for such risk are the winds from the sector 020° – 100° during December and January ; yet winds from part of this sector, i.e. 020° – 070° , seem to give no special risk during October and November or during February and March. During the former period winds from south or east are more important. The probability of low ceilings with southerly or south-westerly geostrophic winds is small during October and November but not in the later parts of the winter half-year.

The extent to which an aerodrome is liable to low ceilings with winds from a given direction is dependent not only on local factors, e.g. slope of ground or shelter afforded by hills, but also on the most common characteristics of air arriving from that direction (especially with regard to humidity near the surface, and stability). The rather confusing variations mentioned above seem most likely to arise because characteristics which may be typical of air from a certain direction during one part of the winter half-year are not so during another. In particular, characteristics of continental air masses can be expected to change considerably between October and March.



(a)



(b)

PLATE I (a)–(d)—FOUR STAGES IN THE DEVELOPMENT AND DECAY OF A FUNNEL CLOUD OBSERVED FROM PLAYA DE ARO, SPAIN ($41^{\circ} 48' \text{N}$, $3^{\circ} 05' \text{E}$), AT 1615 GMT
2 SEPTEMBER 1965

The camera was facing south-west and the time interval covered by the sequence is 12 minutes. The funnel cloud is about $\frac{3}{4}$ mile distant and its diameter at the base in Plate I (b) is 30 yards. The cloud base is estimated to be at 2000 feet. The disturbance occurred in extremely unstable air near the centre of an intense cold pool over the western Mediterranean. The central 1000–500 mb thickness (545 decametres) was well below the 5-year minimum for the time of year.



(c)



(d)

Photographs by T. C. Hughes

Whatever the reasons for features shown in the lower diagrams of Figure 2 it seems significant for the forecaster that with geostrophic winds in the range 7-24 knots there are broad sectors of wind direction which give a special risk of a low ceiling (the sectors varying according to month) ; in contrast, with winds in the same range of speed but from the sector 290°-010° the likelihood of a low ceiling is small during any of the months October to March. Table I shows the contrast. With the use of broad sectors it has been possible to show the effects for two ranges of wind speed without having to base individual results on small numbers of observations.

TABLE I—PERCENTAGE PROBABILITIES OF LOW CLOUD CEILING AT HEATHROW ACCORDING TO THE GEOSTROPHIC WIND FOR WINDS FROM SELECTED SECTORS

Months	Geostrophic wind	Percentage probability of ceiling :	
		below 300 feet	below 600 feet
October/ November	7-14 knots		
	080°-160°(352)	16	20
	290°-010°(399)	5	7
	15-24 knots		
	080°-160°(333)	7	11
	290°-010°(541)	0	0.4
December/ January	7-14 knots		
	050°-100°(167)	35	44
	290°-010°(294)	12	15
	15-24 knots		
	050°-100°(216)	5	17
	290°-010°(491)	0.4	2
February/ March	7-14 knots		
	200°-250°(223)	11	20
	290°-010°(345)	4	6
	15-24 knots		
	200°-250°(341)	4	12
	290°-010°(489)	1	2

Figures in brackets give the number of occasions within the range.

The contrasts between the two chosen sectors are large with winds in the range 15-24 knots. But even when the geostrophic wind is as light as 7-14 knots the probability of a low ceiling with a wind from the sector 290°-010° is only about one third of that with a wind from another broad sector. One might expect, on synoptic grounds, that with slack pressure gradients the direction of any light wind would be of little importance because the association of individual wind directions with specific advective tendencies or air masses would be only weak. Forecasters at Heathrow have commented on the relative freedom from low ceilings with slack pressure gradients when the geostrophic wind is from the north-west. They attribute this to the general slope of ground from the crest of the Chiltern Hills (some 20 miles to the north-west and about 750 feet above MSL) down to the aerodrome. It had been noted that on radiation nights the formation of fog appears to be delayed if there is a slight wind from north-west ; fog forms some distance to the south-east and when the aerodrome is eventually affected it is as a result of the fog spreading from this direction, i.e. against the general drift of air.

The results of Table I suggest that even when the pressure gradient is expected to be slack, if a forecast can be made of the direction of the geostrophic wind — at least between broad limits — this would be of help in assessing the likelihood of a low ceiling.

Variations according to time of day.—Diurnal variations cannot be shown in detail because only three-hourly observations were used. Figure 3

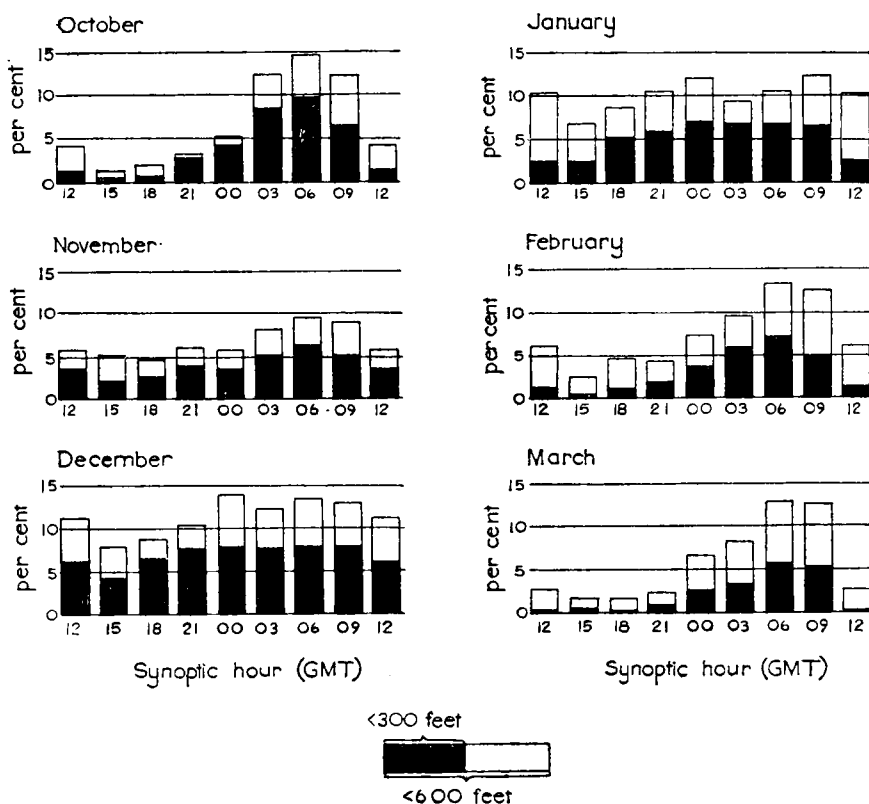


FIGURE 3—PERCENTAGE PROBABILITIES OF CLOUD CEILING BELOW 300 FEET AND BELOW 600 FEET FOR EACH SYNOPTIC HOUR DURING THE MONTHS OCTOBER TO MARCH AT HEATHROW

shows that (as would be expected) low ceilings are least frequent in the afternoon and that the smallest diurnal variations are in the middle of the winter. In the diagrams the frequencies are arranged from midday to midday instead of from midnight to midnight so that changes through the evening and night can be readily appreciated. In October, November, February and March low ceilings become more likely as the night progresses. In December and January, however, the frequency of low ceilings does not increase between midnight and 0900 GMT, indeed the frequencies of ceiling below 600 feet are a little less at 0300 GMT than at midnight. This is a rather puzzling feature. It is as if, during the mid-winter period, a potentiality for formation of fog or stratus overnight is realized by about midnight and any further nocturnal cooling makes little difference. On individual occasions fog or stratus must develop or disperse between midnight and 0900 GMT but one would not expect frequencies based on 13 winters to give a misleading impression of the general trend. The fogs included in the frequencies were, of course, only those in which the sky was obscured and so would tend to be water fogs rather

than smoke fogs. It is interesting to note the similarities month by month between the diurnal trends in low ceiling and those in poor visibility — Figure 3 can be compared with histograms given by Evans² to show fog frequencies at Heathrow.

Conclusions.—Though the results are interesting it is disappointing that the purely local characteristics cannot readily be distinguished from characteristics which are related to synoptic tendencies and so must be more general. Similar analyses for other aerodromes would be valuable in helping to make such a distinction and in showing effects where the surrounding terrain is more rugged than at Heathrow.

Acknowledgement.—The author is grateful for comments and suggestions from Mr. T. N. S. Harrower, Mr. W. D. S. McCaffery, Mr. G. A. Howkins and forecasters at London (Heathrow) Airport.

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SOME EMPIRICAL RELATIONSHIPS CONCERNING THE INTENSITY OF DIRECT SOLAR RADIATION

By R. W. GLOYNE and M. E. KYLES

Introduction.—There is an increasing interest in radiation climatology as applied to the biological sciences such as agriculture and forestry. Thus the paucity of information on solar radiation in the British Isles — particularly north of a line from about the Wash to South Wales — renders it essential to explore any means whereby the available data can be fully exploited. Two empirical results produced by Lauscher¹ in 1934 give helpful indications of what can be deduced from the noon value of the intensity of the vertical component of the direct solar beam when skies are clear. Data from Kew have now been examined in the light of Lauscher's results and it is planned to analyse in a similar way a short period of data from Lerwick on total and diffuse radiation received on a horizontal surface.

The purpose of the present note is :

- (i) To test Lauscher's results on an extensive series of data in Britain. The data used were those given by Stagg² on the direct solar radiation at normal incidence at Kew, and covered a period which was different from the period used by Lauscher.
- (ii) To detect any seasonal variations which may be relevant to Lauscher's results. Solar declination at noon at mid-month was used as a measure of the season.
- (iii) To see if results similar to those of Lauscher could be obtained for conditions when skies were not clear. The data examined were those given by Stagg for groups of data classified according to various levels of recorded radiation including a group containing all available days of recorded radiation.

Lauscher's results.—The intensity of the vertical component (V) of the direct solar beam has a value V_n at local noon and a mean daily value V_{mean} . Lauscher's first result stated that the ratio (L) of the mean daily value of V and the local noon value obeyed the relationship

$$L = V_{\text{mean}}/V_n = 0.55$$

Lauscher's two results were applicable under clear skies for latitudes 0 to 70°N for all times of the year. The second result related the intensity at various times of day with the intensity at local noon. He showed that if the time of day was converted into an interval from local noon and expressed as a percentage of the half-day length (i.e. if the scale for time were normalized), then the intensity of the vertical component of the direct solar beam could be expressed as a percentage of the noon intensity (Table I).

TABLE I—RELATIONSHIP (FOR CLEAR SKY CONDITIONS) BETWEEN THE TIME OF DAY AND THE INTENSITY OF THE VERTICAL COMPONENT OF THE DIRECT SOLAR BEAM (FROM LAUSCHER).

Time of day*	0	5	10	15	20	25	30	35	40	45	
Intensity†	100.0	98.6	97.0	95.1	92.7	89.5	85.0	78.8	72.3	65.3	
Time of day*	50	55	60	65	70	75	80	85	90	95	100
Intensity†	58.3	51.2	44.0	36.8	29.7	22.7	16.0	10.5	6.1	2.5	0.0

* Expressed as a percentage of the half-day length from local noon.

† Expressed as a percentage of the corresponding intensity at local noon.

The Kew data.—Sets of mean daily values for each month were derived by Stagg for different groups of data of normally incident radiation from the direct solar beam. It was found necessary to classify according to the recorded radiation because of the difficulty of detecting by eye thin cirrus cloud and differences of air clarity either of which has a marked effect on the recorded radiation. The data were grouped as *A*, *B*, *C* and *D* as follows, and Stagg gave average daily totals of normally incident radiation for the various groups:

- A* All days: all available days of recorded radiation in each month (1933–46).
- B* Days of high radiation: in each month of a given name a limited but representative number of complete days of radiation were selected for their high total daily radiation (exceeding a value separately chosen for each month). These formed about 8 per cent of the total number of available days.
- C* Days of highest recorded radiation: from group *B* were selected a very limited number of days to form groups of days with the highest daily radiation recorded. These amounted to 5 or 6 days for a month of a given name and formed about 1 per cent of the total number of available days.
- D* Maximum recorded (or ceiling) values for daily radiation: by selecting peak values of recorded radiation on exceptionally clear occasions, maximum radiation values at Kew were estimated for each month (mean hourly and daily totals). The durations of these peak or ceiling intensities might only be for a few minutes and were obtained by selecting the highest rate of input recorded within periods of 60 minutes ending each hour (local mean time (LMT)). The peak values were related to the sun's altitude and a smooth curve obtained from which mean hourly and daily totals were computed for each month.

The intensity at local noon.—In his sets of mean daily values Stagg gave mean values over an hour ending at each exact hour local time and his values were thus centred at the half-hour (LMT). For testing Lauscher's results the intensity at local noon is required and a number of possible procedures were employed for obtaining this information.

The data for intensity of normally incident radiation against LMT given by Stagg in his tables VII, VIII, IX and X (respectively for classes *A*, *B*, *C*, *D*) were plotted and an estimate of the local noon value obtained in the following ways :

- (a) The intensity/time curve constructed from readings centred at the half-hour was extended to intersect the noon axis. Because of certain irregularities in the curves for some months (see also Figure 2) attention was concentrated on whichever of the half-days (pre- or post-noon) gave rise to the more regular trend.
- (b) The course of curves (a) for two hours or so about local noon was adjusted, if so required, to run approximately parallel to that for the 'ceiling' values — class *D* — which were assumed to define the idealized form of the relationship.
- (c) The values of the intensity at noon obtained by the free-hand extrapolation in (a) were plotted against solar declination in Figure 1 for classes *A* and *D* and in Figure 2 for classes *B* and *C*. Smooth curves were

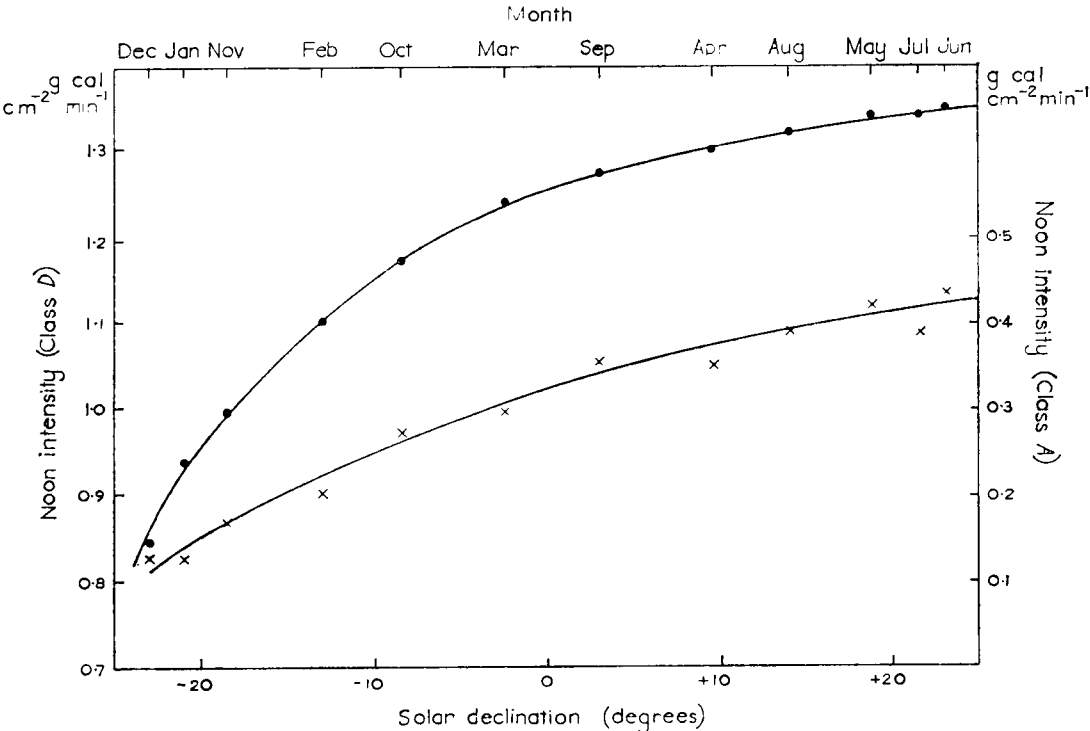


FIGURE 1—NOON INTENSITY OF DIRECT SOLAR BEAM AT NORMAL INCIDENCE AT KEW PLOTTED AGAINST SOLAR DECLINATION ON MIDDLE DAY OF THE MONTH

—————, Class *D* or 'ceiling days' (left-hand ordinate)
 x ——— x Class *A* or 'all' days (right-hand ordinate)
 (Using data classified by Stagg² as class *A* and *D*.)

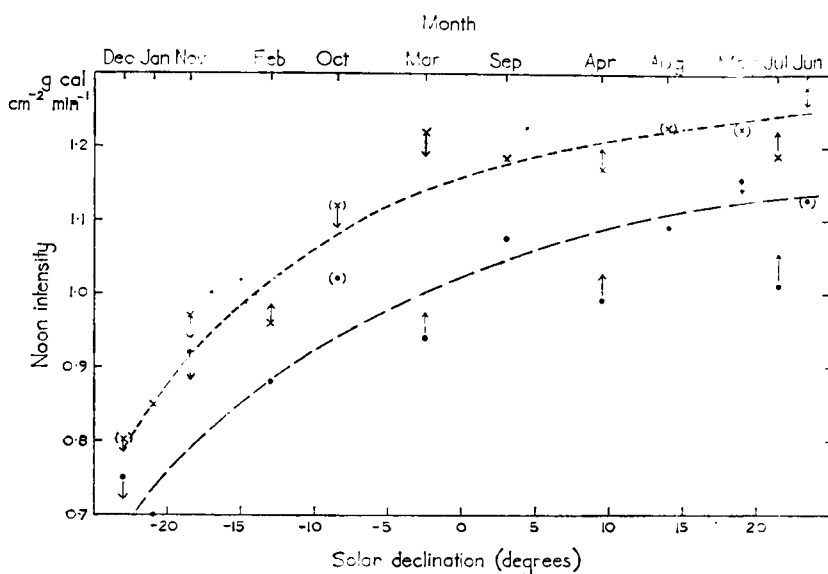


FIGURE 2—NOON INTENSITY OF DIRECT SOLAR BEAM AT NORMAL INCIDENCE AT KEW PLOTTED AGAINST SOLAR DECLINATION ON MIDDLE DAY OF THE MONTH

— · — Class *B* or 'high' radiation days
 x — x Class *C* or 'highest' radiation days
 (Using data classified by Staggs² as class *B* and *C*.)

Upward pointing arrows imply that results are low relative to those in class *D* and downward pointing arrows that results are high.

The existence of a considerable asymmetry of the intensity/time plot about local noon is indicated by brackets round the values.

drawn in accordance with principles described in Appendix I and the noon intensity for a month of given name was read off from the smoothed curve.

A common feature of the diurnal variation of normally incident radiation (particularly with classes *B* and *C*) was a definite asymmetry — the highest values occurring before rather than after local noon. Staggs invoked synoptic arguments to explain this feature. However if results are to be generalized it is obviously necessary to adopt procedures which may tend to minimize any peculiarities dependent upon local and regional factors or on the particular period chosen. These objectives were partially achieved by using various families of curves to obtain adjusted noon intensities for the various classes (see Appendix I).

Extension of Lauscher's first result.—After some trials with the Kew data it was found that the most stable values of L , the ratio between V_{mean} and V_n , were derived directly from the observed quantities. Thus V_{mean} was computed from whichever of the half-days (pre- or post-noon) gave the most regular curve of normal intensity plotted against time, and V_n was obtained by free-hand extrapolation of the intensity-time curve as in method (a) page 363.

Computed values of L for the four classes discussed are given in Table II along with smoothed values for classes *A*, *B* and *D*. For class *A* the scatter about the mean value of 0.50 is appreciable but a smooth curve of the same form as for class *D* can reasonably be constructed. Furthermore for class *B* it is possible to discern a similar underlying trend and tentative smoothed values are included in Table II. A similar regularity does not emerge from the plot

TABLE II—LAUSCHER RATIO L FOR KEW FOR VARIOUS CLASSES GIVEN BY STAGG

Class	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Lauscher ratio L													
<i>D</i> (Actual)	0.550	0.557	0.558	0.558	0.547	0.546	0.547	0.554	0.560	0.558	0.544	0.536	0.551
(Smoothed)	0.543	0.555	0.559	0.557	0.551	0.544	0.547	0.556	0.559	0.557	0.548	0.536	0.551
<i>A</i> (Actual)	0.511	0.503	0.499	0.503	0.495	0.519	0.487	0.513	0.524	0.506	0.471	0.490	0.502
(Smoothed)	0.486	0.500	0.509	0.509	0.503	0.494	0.498	0.507	0.511	0.505	0.491	0.482	0.500
<i>B</i> (Actual)	0.500	0.510	0.520	0.510	0.510	0.500	0.500	0.490	0.510	0.530	0.500	0.510	0.510
(Smoothed)	0.500	0.515	0.520	0.510	0.505	0.495	0.500	0.510	0.515	0.520	0.500	0.495	0.510
<i>C</i> (Actual)	0.500	0.500	0.520	0.530	0.500	0.520	0.530	0.530	0.490	0.550	0.540	0.510	0.520

of values for class *C* and only the computed values appear in Table II. A partial explanation for this anomalous behaviour may be that this group lacks the rigorous selection procedures adopted for class *D* and also because it suffers from being a very small 1 per cent sample.

The annual mean value of L increases consistently from class *A* to class *D*.

In Figure 3 monthly values of L are plotted against solar declination at mid-month for classes *A* and *D*. These curves suggest a seasonal variation of L and it is clear that the curve for class *D* is sufficiently smooth and well defined to justify using it to obtain a value of L for each month. The mean annual value of L is almost exactly 0.55 as given by Lauscher.

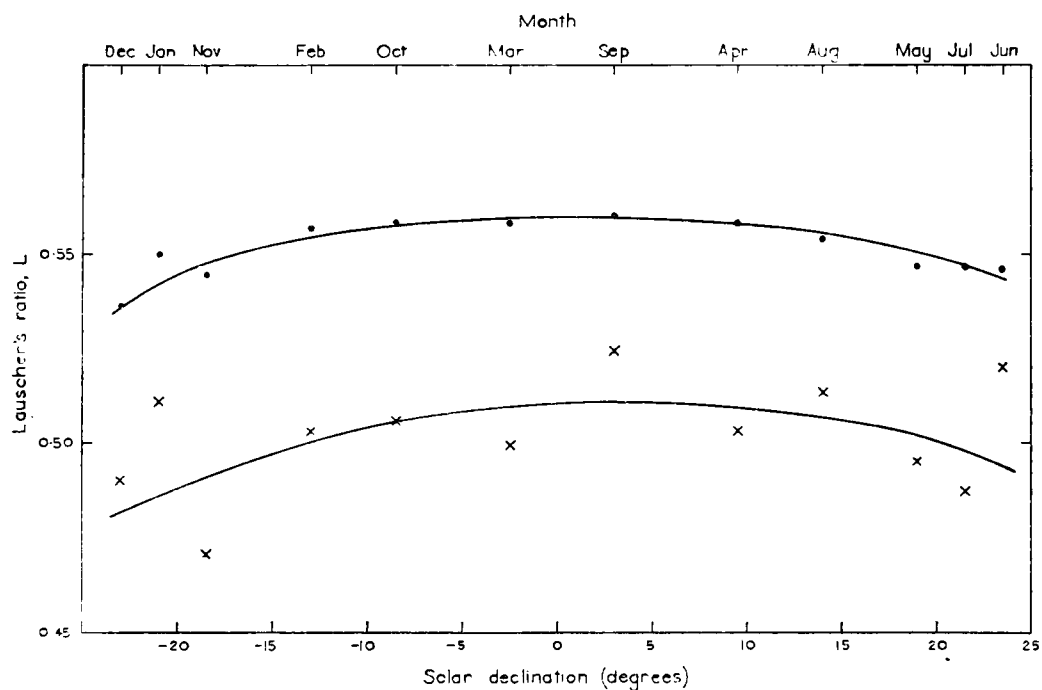


FIGURE 3—LAUSCHER'S RATIO, L , FOR EACH MONTH OF THE YEAR ON CLASS *D* AND CLASS *A* DAYS AGAINST SOLAR DECLINATION

—•—•— Class *D* or 'ceiling' days
 x—x—x Class *A* or 'all' days
 (Using data classified by Stagg² as class *A* and *D*.)

Extension of Lauscher's second result.—The Kew data were examined to obtain the equivalent of Lauscher's second result which, for various times of day, quoted the vertical component of the intensity as a percentage of that at noon. The value of V_n at Kew was taken as the value calculated from

the noon intensity found by the procedure (a) described on page 363. The intensity (V) at the various times of day was derived from whichever half-day gave the most regular plot of normally incident intensity against time. The intensity as a percentage of that at noon was plotted against the normalized time scale for classes D and A irrespective of time of year (Figures 4 and 5). It is clear that Lauscher's findings (plotted in Figure 4) are closely followed for class D data and that a similar, almost equally close, relationship holds for class A data.

For a slightly more detailed analysis plots were prepared for each class of data and for each month. Smooth curves of the form shown in Figures 4 and 5 were drawn through the plotted points. The agreement between the plots for successive months was such as to permit the following aggregation :

Class D : all months together ;

Class A, B and C : March to August together as a summer half-year, and
September to February together as a winter half-year.

Pearson Type II Curves (Appendix II) were then fitted to the various aggregations. Sufficient points to define these curves are given in Table III which may be compared to Lauscher's findings in Table I. It will be seen that the differences between the several classes of data are quite negligible for periods around noon within an interval of 20 per cent of the half-day.

TABLE III—INTENSITY OF THE VERTICAL COMPONENT OF THE DIRECT BEAM AS A PERCENTAGE OF THE VALUE AT LOCAL NOON IN RELATION TO THE PERIOD FROM LOCAL NOON EXPRESSED AS A PERCENTAGE OF THE HALF-DAY (USING DATA FOR KEW GIVEN BY STAGG)

	Period from local noon (percentage of half-day)													
	0	5	10	20	30	40	50	60	70	80	90	95	100	
Class	<i>percentage of intensity at local noon</i>													
<i>D</i>	100	99.5	98.0	92.5	84.0	72.5	58.5	44.0	29.5	16.0	6.0	2.5	0	
<i>C</i>														
Summer	100	99.5	98.0	91.7	82.0	69.3	54.5	39.3	24.5	12.0	3.7	1.0	0	
Winter	100	99.5	98.0	92.0	82.5	70.3	56.0	40.5	25.7	13.0	3.7	1.1	0	
<i>B</i>														
Summer	100	99.5	97.5	90.3	79.0	65.0	49.3	33.7	20.0	9.5	3.0	1.1	0	
Winter	100	99.5	97.7	91.5	81.7	68.7	54.0	38.5	23.5	11.3	2.5	0.7	0	
<i>A</i>														
Summer	100	99.5	97.7	91.0	80.3	66.3	50.7	34.5	19.7	8.0	1.3	0	0	
Winter	100	99.5	97.7	91.5	80.7	67.0	51.5	35.0	19.7	7.7	0.7	0	0	

Summary and discussion.—

1. Lauscher's results detailed on page 362 have been confirmed for Kew for days having ceiling values of incident radiation (Tables II and III).
2. A seasonal variation in Lauscher's ratio L has been detected, though the variation about the mean is probably too small to be of practical significance (Figure 3).
3. Results of the Lauscher type have been derived for data of certain classes defined on page 362 — broadly described as very sunny days and all days (Tables II and III).

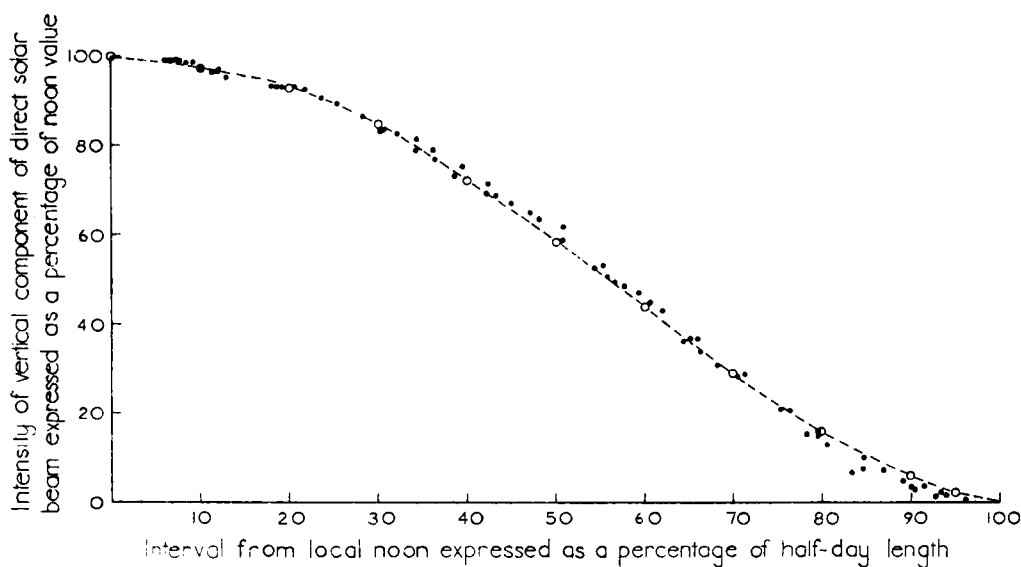


FIGURE 4—INTENSITY OF THE VERTICAL COMPONENT OF THE DIRECT SOLAR BEAM, EXPRESSED AS A PERCENTAGE OF THE NOON VALUE, AGAINST THE INTERVAL FROM LOCAL NOON AT KEW, EXPRESSED AS A PERCENTAGE OF THE HALF-DAY LENGTH, FOR CLASS *D* DAYS

o Points plotted according to Lauscher's second result

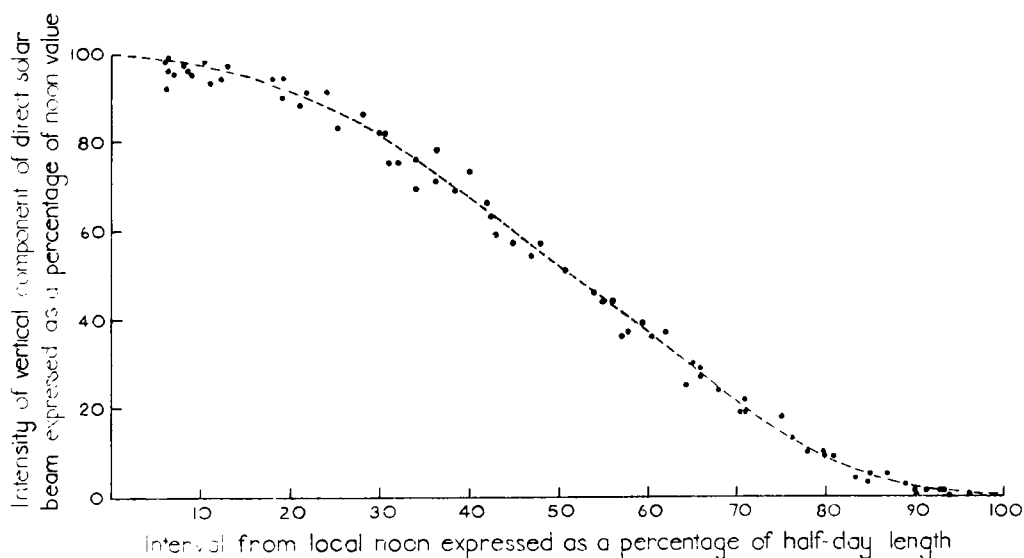


FIGURE 5—INTENSITY OF THE VERTICAL COMPONENT OF THE DIRECT SOLAR BEAM, EXPRESSED AS A PERCENTAGE OF THE NOON VALUE, AGAINST THE INTERVAL FROM LOCAL NOON AT KEW, EXPRESSED AS A PERCENTAGE OF THE HALF-DAY LENGTH, FOR CLASS *A* DAYS

4. Lauscher's second result for clear conditions and similar results derived for data of certain other classes are shown to be closely fitted by a family of Pearson Type II curves (Table III and Appendix II).

5. A set of reasonably satisfactory linear regressions has been derived relating the value of normally incident radiation at noon with the expression $\log (\text{declination} + 25^\circ)$ for the several classes. (Figure 6).
6. Given a reliable estimate of the noon intensity of the direct beam in clear conditions in a locality, empirical relationships of the Lauscher type can probably be employed to obtain useful results. The practical application to localities far from Kew requires that the techniques described be first tested with data from areas whose sky conditions differ appreciably from those of Kew.

Appendix I

Direct solar radiation at normal incidence at Kew in relation to solar declination

In an attempt to obtain a reliable estimate of the intensity at noon, the relationship between this quantity and solar declination at noon at mid-month was examined ; the results were sufficiently informative and useful to merit a brief discussion.

If it is assumed that a smooth curve, such as is obtained by plotting Stagg's 'ceiling' values against local time, represents the type of relationship to be expected when sampling variance is largely eliminated, then two sources of error in the data for classes *B* and *C* can be specified, namely :

- (i) Irregular fluctuations, between months of different name, in the magnitudes of the deviation of the estimated noon values from those obtaining for class *D*.
- (ii) Irregularities in the plot of normally incident radiation against time, namely either unsteady increase from sunrise (or sunset) towards noon, and/or marked asymmetry of the curve about noon.

The values of the normal intensity at noon, obtained by the free-hand extrapolation described (page 363), are plotted against solar declination in Figure 1 (for classes *A* and *D*) and Figure 2 (for classes *B* and *C*). When constructing the smooth curves in the figures, the existence of errors mentioned above was borne in mind and the points were annotated as follows :

- (a) Upward pointing arrows imply that results are low relative to those in class *D* and downward pointing arrows that results are high.
- (b) The existence of a considerable asymmetry of the intensity/time plot about local noon is indicated by brackets round the values.

Obviously greatest weight was given to points lacking these annotations.

Stagg suggested that the radiation quality of (Class *B*) days selected from the months of November, December and (perhaps to a lesser degree) October was probably above the average for the remaining months of the year — remarks consistent with the indications in Figure 2 which also suggests analogous conclusions for other months, such as June and March.

A useful summary for all classes of the connexion between intensity and solar declination is given in Figure 6 which consists of a plot of the noon intensity at normal incidence against $\log x$, where :

$$x = \text{declination} + 25^\circ,$$

the addition of an arbitrary 25° being adopted in order to avoid negative values.

Although all curves are sigmoid in character, a linear least squares solution based upon all available points for declinations equal to or greater than -20°

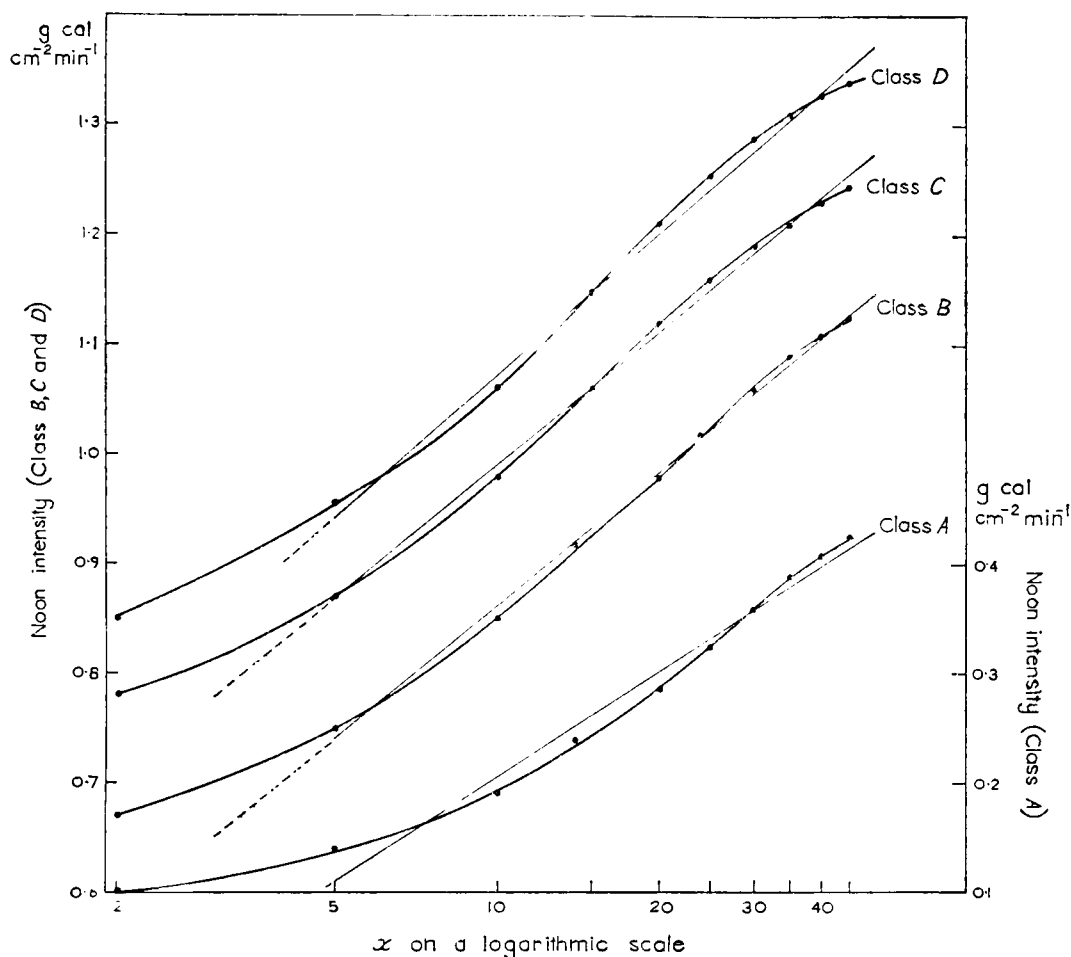


FIGURE 6—RELATIONSHIP BETWEEN NOON INTENSITY OF DIRECT SOLAR BEAM AT NORMAL INCIDENCE AND LOG x AT KEW, TOGETHER WITH LINES OF BEST FIT FOR DECLINATIONS GREATER THAN -20°

$x = \text{declination} + 25^{\circ}$

A All days (1933-46)	B Days of high radiation
C Days of highest recorded radiation	D 'Ceiling' radiation values

(Using data classified by Staggs² as class A, B, C and D.)

The straight lines are the lines of best fit.

(i.e. applying to the period 21 January to 21 November) represented the run of values very satisfactorily. Table IV gives the values of the constants used in the equation,

$$\text{Intensity} = b \log cx.$$

TABLE IV—VALUES OF THE CONSTANTS b AND c IN THE EQUATION, FOR VARIOUS CLASSES

Class	Value of constants	
	b	c
A	0.318	0.44
B	0.412	12.23
C	0.407	27.07
D	0.429	31.88

For the classes A, B, C and D the correlations between $\log x$ and intensity are 0.982, 0.997, 0.994 and 0.997 respectively.

For classes *B*, *C*, *D* the departure from a linear dependence exceeded 2 or 3 per cent only for declinations less than -21° (i.e. between 27 November and 17 January). For class *A* and for declinations less than about -19° (i.e. between 18 November and 24 January) the linear assumption would be misleading and give a relative error of 10 per cent or more. There is a tendency for *b*, the gradient of the line, to increase from class *A* to class *D*, suggesting some underlying physical factor — however the gap between the mere 8 per cent of days constituting class *B* the to ‘all’ days of class *A* renders arguments on these lines hazardous.

Appendix II

It was required to fit a series of curves having the following properties :

- (i) an assumed complete symmetry about the vertical (local noon) axis,
- (ii) a significant degree of negative kurtosis, and
- (iii) a high degree of contact at the lower end.

After extensive trials with a number of possible analytical expressions, it was judged that one of the form given below, i.e. a Pearson Type II-curve, fitted best with the minimum of parameters, namely

$$y = \left(1 - \frac{t^2}{a^2}\right)^m$$

where

y = ratio of the intensity of the vertical component of solar radiation at interval *t* from local noon, to the intensity at noon,

and *t* = interval from noon expressed as a percentage of the half-day length.

Based upon values read from the smoothed curve of the intensity of the vertical component against ‘time’ at ten equally spaced points on the abscissa, (i.e. at 5 per cent, 15 per cent, etc. of the half-day length), the numerical values of associated pairs of the parameters *m* and *a* are as follows :

Class	<i>m</i>	<i>a</i>
<i>D</i>	2.035	103.9
<i>C</i> (summer)	2.188	101.7
<i>C</i> (winter)	2.063	100.9
<i>B</i> (summer)	2.853	106.7
<i>B</i> (winter)	2.162	100.4
<i>A</i> (summer)	2.188	96.8
<i>A</i> (winter)	2.036	94.5

There is no obvious systematic variation in the values of *m* and *a* although when the curves are plotted they form a set following the sequence indicated above. The divergence, at any point, between the original smoothed curve and the associated Type II-curve did not exceed one part in 100 of the noon value.

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2. STAGG, J. M. ; Solar radiation at Kew Observatory. *Geophys. Mem., London*, No. **86**, 1950, p. 3.

METEOROLOGY AT THE UNIVERSITY OF READING

By PROFESSOR R. C. SUTCLIFFE, C.B., O.B.E., F.R.S.

It was not long after the Headquarters of the Meteorological Office had been brought together at Bracknell in 1961 that the authorities of the University of Reading showed an interest in the establishment of a department of meteorology, an enterprise to which the Director-General of the Office gave all the official encouragement he could and to which I as Director of Research was equally well disposed. It has long been felt that meteorology in British universities could justifiably be expanded, although where and how was less obvious, and the close proximity of Bracknell to Reading seemed a particularly favourable factor which would allow of co-operation in various directions. There is no need to list here the many hypothetical ways in which the one institution might benefit from good relations with the other but rather, now that the University department has been created, we have the practical task of making the most of the opportunities. Having long been interested in meteorological education I am naturally delighted to be given the chance to make a tangible contribution.

When meteorology is considered as a university subject a number of embarrassing facts have to be faced, facts which are in part peculiar to the subject and in part peculiar to the conditions in the country concerned. The science is the foundation of a useful and thoroughly well-established professional service but it is and presumably must remain a comparatively small profession, smaller by one or two orders of magnitude than the large scientific technical professions of medicine, engineering or agricultural science : it has been too small in Britain to make any exigent demand for vocational training departments. Furthermore the profession is a near-monopoly of the state Meteorological Office offering no guarantee of employment to anyone who may choose to study the subject at a university. Again, meteorology, neglected by physicists, has been adopted and much studied by departments of geography, and rightly so, for weather and climate are relevant considerations for the geographer whether his interest is physical, historical, social or economic. But the geographer cannot, or at least does not and I believe should not, assume responsibility for the training of meteorological specialists or for the main development of the subject as a branch of science which steadily becomes more dependent on laboratory and mathematical physics.

In planning meteorological teaching at Reading I have taken it as axiomatic that a comprehensive course must be basically a course in theoretical, experimental and observational physics. The empirical exploration and analysis of the wide range of specific phenomena which uniquely define meteorology must certainly not be despised ; the aim is to have knowledge and understanding of weather and climate and not merely to exercise skills in mathematics or laboratory physics. Nevertheless meteorology belongs to geophysics ; it is a branch of physical science and it cannot get very far without the basic tools. Ideally, no doubt, meteorology is most effectively studied in graduate schools following on from a degree course in basic science but it is not easy to attract sufficient students at that stage in their careers and I have thought it desirable to take recruits immediately from school at a time when many young people seem to have a natural inclination towards the subject.

The outcome of all this is then a first-degree course for honours B.Sc. with meteorology, mathematics and conventional physics receiving roughly equal attention throughout the three years. This is the first time that a comprehensive first-degree course, or any course in meteorology continuing through three years, has been offered in a British university and I believe the time available will suffice for the subject to be tolerably well covered. The graduate will still be recognizably a physicist, in fact and in name, but one who has the advantage of having specialized in an environmental science and so may find a vocation along many other avenues if professional meteorology is not his final choice.

In the course of the next two or three years the plan is to build up a viable department with six or seven permanent teaching staff so that individually the share of undergraduate teaching will be light and will leave opportunity for the development of an effective research school. The first fruits of the close connexion with the Meteorological Office is the promise, with official approval, of very substantial help in lecturing during the first year from research staff in the Office. Dr. R. Frith, Mr. A. Gilchrist and Dr. F. B. Smith, all established research scientists, have each undertaken to provide a regular series of lectures within the agreed syllabus. The undergraduate course is thus getting off to a flying start.

A postscript may be of interest. It is possible within the University's regulations to enrol for research, with a view to the Ph.D. degree, graduates — from this or other universities — who may pursue their research entirely extramurally, subject to some degree of supervision by the university tutor. I shall, as would be expected, be especially happy if we can somehow take advantage of this facility so that I may assist to their doctorates members of the Office staff whose private or official research work is acceptable also to the university, as, in most cases, it must surely be.

551.5:061.3

THE FOURTH SESSION OF THE COMMISSION FOR AEROLOGY, BRUSSELS, 1965

The Commission for Aerology of the World Meteorological Organization (WMO) held its fourth session in Brussels from 6 to 19 July 1965. The Commission is primarily concerned with ensuring the international co-ordination which is necessary for many aspects of meteorological research and, in particular, for recommending programmes of observation necessary for the study of large-scale phenomena and for arranging the publication and exchange of the meteorological data which are required for studies of the atmosphere.

During the course of the meetings a wide range of meteorological research came under review, but recommendations for new or augmented observational programmes concerned mainly observations of ozone and the high atmosphere. In particular a world-wide network of stations to determine winds in the high atmosphere from the drift of meteor trails has been proposed, and further study of the drift of ionization in the 'E' layer. Current arrangements to watch for signs of rapid warming of the stratosphere in winter and to notify

the occurrence of such warming to those who wish to carry out special research programmes were discussed, and it was recommended that they should continue until 1970.

Subjects in which the Commission showed a new and lively interest were (a) atmospheric pollution, (b) the exchange and storage of data in forms suitable for computer use and (c) tropical meteorology. Working groups have been established by the Commission to keep all these topics under review.

In discussing atmospheric pollution it was evident that delegates considered that this problem could no longer be considered solely as a local matter of the environment of a single factory or city, but that there was a need to monitor the pollution of the atmosphere on a much wider scale. The new Working Group will seek to establish comparability in observing techniques and will make proposals for establishing and monitoring the background contamination of the atmosphere as a whole.

The Commission's concern with the exchange of data in the form of punched cards, paper tape, magnetic tape, etc. can be understood at a time such as the present when technological innovation makes the maintenance of standards of form and format in such media particularly difficult. The Working Group which will review the problem can also be expected to keep in close touch with the development of the scheme for World Weather Watch in the hope that the World, Regional and National Weather Centres which it includes will maintain comprehensive archives of meteorological data in a form in which they can readily be used for research.

In tropical meteorology it is hoped that WMO may stimulate and organize an augmented observational network in some part of the tropical belt.

Among the more specific recommendations made by the Commission for Aerology, was the decision to make no change in the definition of the tropopause for another 4 years at least, despite occasional criticisms of it. Emphasis was also placed on the desirability of meteorological observations from high towers (television masts, etc.) to provide proper understanding of the boundary layer needed for numerical forecasting and studies of the general circulation.

It may be noted that the increased international activity in meteorological research has had the result that many questions are referred to the President of the Commission between the sessions which are held at intervals of 4 years. The Commission therefore formed an Executive Working Group of five members which, it is hoped, will meet annually to advise the President on current problems.

Delegates to the fourth session of the Commission for Aerology greatly appreciated the remarkable hospitality of their Belgian hosts and of the excellent arrangements made for the meetings which contributed greatly to their success.

J. S. SAWYER

NOTES AND NEWS

Meteorological Magazine : increase in price

We regret that owing to the need to recover the full cost of postage it will be necessary to increase the price of the *Meteorological Magazine* beginning with the January 1966 issue. The net annual subscription will become 41s. including postage.

Royal Netherlands Meteorological Institute

Professor D. W. Bleeker succeeded Mr. C. J. Warners as Director-in-Chief of the Royal Netherlands Meteorological Institute on 1 September 1965 and has also been designated Permanent Representative of the Netherlands with the World Meteorological Organization.

India Meteorological Department

Mr. C. Ramaswamy succeeds Mr. P. R. Krishna Rao as Director General of Observatories, India Meteorological Department. Mr. Krishna Rao retired on 24 July 1965.

METEOROLOGICAL OFFICE NEWS

Retirement presentation to Sir Graham Sutton, C.B.E., F.R.S.

At a ceremony held in the Lecture Theatre at Bracknell Headquarters on Wednesday 29 September Dr. A. C. Best, Director of Services, made a presentation on behalf of members of the Office to Sir Graham Sutton on the occasion of his retirement as Director-General. Mr. W. C. Curtis, Assistant Secretary in F6 (Air) represented members of the Permanent Under Secretary's Department who had also contributed to the presentation.

Sir Graham paid tribute to his immediate advisers in the Higher Directorate, and to his personal staff and many others, but stressed the loyal services rendered by the staff as a whole. He intimated that he intended to purchase a stereogram with the money subscribed for his retirement gift.

Lady Sutton spoke of her happy associations with the social activities of the Office and of how she had been made welcome by all concerned. On behalf of Sir Graham and herself she then presented to the Office a silver rosebowl, to be awarded annually to the individual making the most worthy contribution to the social life of the Office. Mr. C. W. G. Daking as Chairman of the Meteorological Office Social and Sports Committee accepted this handsome gift to the Office (Plate II) and emphasized how much members of the staff appreciated the deep interest taken by Sir Graham and Lady Sutton in the social activities of the Office. Miss Wordsworth presented a bouquet to Lady Sutton, and the assembly, at the invitation of Sir Graham, then adjourned to the Restaurant for a more informal farewell party.

G.W.G.D.

REVIEWS

General relativity and cosmology (International astrophysics Series, Vol. 4), by G. C. McVittie. 9½ in × 6 in, pp. xii + 241, Chapman and Hall Ltd., 11 New Fetter Lane, London EC4, 1965. Price: 50s.

Dr. G. C. McVittie is well known to meteorologists for his active interest in some of their basic problems of the representation of dynamical theory in suitable co-ordinate systems. His papers in the meteorological journals show admirable clarity, directness and simplicity and these are the hallmark of this second edition of *General Relativity and Cosmology*. As the author remarks, the plan of the book is similar to that of Tolman, focusing attention on the mathematical preliminaries, on the special and general theories and then dealing with gas dynamics and model universes. There is, of course, much new material both theoretical and observational; the theory of gas dynamics is due in a large part to the author himself, as is the working out of the details of the model universes in order to test the predicted properties against observation.



Photograph by G. A. Corby

PLATE II—SIR GRAHAM SUTTON AND LADY SUTTON WITH THE CHAIRMAN OF THE METEOROLOGICAL OFFICE SOCIAL AND SPORTS COMMITTEE, MR. C. W. G. DAKING (LEFT).

The rosebowl will be awarded annually to the individual making the most worthy contribution to the social life of the Office (see p. 374).



Photograph by P. Vella

PLATE III—LENTICULAR LEE-WAVE CLOUDS AT GIBRALTAR EARLY IN THE EVENING
ON 27 DECEMBER, 1964

However, the main interest to the dynamical meteorologist undoubtedly lies in the middle chapters on gas-dynamics; hydrodynamics may be a more familiar term. These chapters give a new slant on hydrodynamical theory and indeed on possible methods of solving the equations. The author sets out to find functions which determine the density, pressure and velocity vector identically satisfying the equations of motion and continuity; the thermodynamic equation would then provide a differential equation for the function, with initial and boundary conditions specified. Perhaps this attack is well known to workers in the field of relativity. I have not seen it in meteorological literature; it may not be possible to adopt this method for our problems but at least it makes us think about them in a new way.

E. KNIGHTING

Atmospheric pollution: its origins and prevention, 3rd revised edition, by A. R. Meetham, D. W. Bottom and S. Cayton. 9 in×6 in, pp. xii+301, *illus.*, Pergamon Press, Headington Hill Hall, Oxford, 1964. Price: 70s.

The second edition of this book was reviewed in this magazine in November 1956.* The appearance of a third edition, within 12 years of the original publication, is adequate testimony both to the demand for a comprehensive technical account of air pollution and to the quality of this book in meeting the demand. The new edition has three authors, Dr. Meetham having been joined by D. W. Bottom and S. Cayton who are experts in the public health aspects.

The period since the notorious London smog, which occurred in 1952, has been one of sustained activity in the study and prevention of air pollution and in a number of countries measures have been taken in attempts to bring the problem under control. In the United Kingdom, for example, the Clean Air Act, in conjunction with earlier legislation such as the various Alkali Acts, has already given good results in reducing pollution levels. Clearly, governmental action on these lines provides an effective stimulus to basic studies and research in the many and complicated aspects of air pollution.

This book which, one supposes, will continue to be referred to as 'Meetham's book' is a thorough revision of earlier editions and contains much new material. As far as can be judged by a reviewer with rather specialized interests in the subject, considerable pains have been taken to cover the whole field in as up-to-date a manner as possible. The subject is covered in an ordered sequence. The first four chapters after the introduction cover the different kinds of fuel, then follow four chapters on the methods and appliances—boilers, furnaces, etc.—by means of which fuel is consumed. Succeeding chapters then deal with pollution and its many complicated problems—constituents, detection and measurement, the varying pattern of distribution, meteorological considerations, effects on health and materials, preventative measures. Finally there is a chapter on the law and its administration, mainly concerned with English law and its implementation, but also containing a review of anti-pollution legislation in other industrial countries.

This book provides an excellent general account of air pollution. It does not replace specialized texts but, aided by bibliographies appended to each chapter, provides helpful pointers to those who wish to go more deeply. Specialists would themselves find this book invaluable for background reading. The book is very well produced.

P. J. MEADE

*MEADE, P. J.; Review of *Atmospheric pollution: its origin and prevention*, 2nd edn. *Met. Mag.*, London, **85**, 1956, p.348.

Atlantic hurricanes, by G. E. Dunn and B. I. Miller. 9½ in × 9 in, pp. xx + 377, *illus.*, Louisiana State University Press, Baton Rouge 3, La., 1964. Price: \$7.50.

This book was first published in 1960; the content of this revised edition is essentially the same as that of the original but with a few additions to bring it up to date. These are descriptive accounts of all the hurricanes of recent years, and a section on the detection and forecasting of hurricanes including the use of meteorological satellites.

There is much in the book that will have a wide appeal, notably some accounts of personal experiences on the ground and in the air in the central parts of violent hurricanes, including some aerial penetrations into the eyes of storms. Some sections have the flavour of popular magazine articles, for example, the opening transcription of a coded hurricane message followed by its decode, and a paragraph on "why hurricanes are given girls' names". Other parts of the book will be meaningful only to the professional meteorologist.

The first five chapters cover well-known ground, including descriptions of hurricanes, seasons and locations of their occurrence, and the associated weather; new material includes some charts of rainfall distribution along the tracks of particular hurricanes.

Then follow six short chapters of a more technical nature, concerned with the energy of the hurricane, its life history, and observing and forecasting techniques. The observational study of hurricanes has advanced in recent years with the help of radar and organized aircraft surveillance, and satellite photography has led to earlier detection; nevertheless, hurricane forecasting still appears to depend much on experience and judgement. No satisfactory method has been devised for the numerical forecasting of hurricanes, neither does a model emerge to enable the energy transformations of the hurricane to be treated quantitatively.

Two chapters deal with the destructive forces of the hurricane — winds, tides and floods — and some practical advice on the action to be taken when one's home is threatened. This ranges from long-term considerations of building construction and choice of site to short-term advice suggestive of preparing for a siege when the hurricane strikes. Then, after a descriptive chapter about some individual hurricanes of the past 10 years, the readers' thoughts are again turned towards technical matters with a recapitulation of present knowledge and recent advances in hurricane research. As is perhaps inevitable with systems whose detailed structure is so little known, no clear line of future progress is indicated.

The book concludes with a number of appendixes listing all hurricanes of which there are records, with brief notes on each mostly relating to casualties or damage. An earlier work *Hurricanes* by Tannehill included a chronological account of all hurricanes between 1901 and 1955; the present work continues this account over the period 1956 – 63.

The book can be recommended to a wide circle of readers: to dynamical meteorologists because the hurricane problem is clearly presented; to the climatologist because of the wealth of facts and figures about hurricanes; and to the non-professional reader because of the lively descriptions of hurricanes and some striking illustrations of hurricane damage and of hurricanes seen from aircraft.

A. G. FORSDYKE

Humidity and moisture: Volume one, Principles and methods of measuring humidity in gases, edited by Robert E. Ruskin. 10½ in × 7 in, pp. xv + 687, *illus.*, Chapman and Hall Ltd., 11 New Fetter Lane, London EC4, 1965. Price: £12.

This book is the first part of a four-volume work representing the expanded proceedings of the 1963 International Symposium on Humidity and Moisture Control held in Washington, D.C. It consists of a selection of papers read at the symposium, an author index and a comprehensive subject index. Each paper is reproduced with the minimum of editing and with its original references. The papers are grouped under six general headings according to the principle of the method of measurement described.

Section I, Psychrometry, contains 11 papers which show that there is room for new techniques even in this old and well-established method of measurement. Of particular interest to the meteorologists are 2 papers describing methods of improving the accuracy and convenience of the psychrometer in 'difficult' conditions. One dealing with the problem of measurement in a hot, dry atmosphere describes a method of precooling the water supplied to the wet bulb. In the other paper it is suggested that the difficulties of maintaining an ice bulb can be avoided by heating the air taken in to the psychrometer to raise the wet-bulb temperature above 0°C. This does not, of course, alter the dew-point.

Section II, Dew-point Hygrometry, also contains 11 papers and reflects the considerable effort of recent years, particularly in the U.S.A., to perfect a convenient and accurate dew-point/frost-point hygrometer. There is a good paper on the basic process of the dew-point hygrometer; the remaining papers describe instruments ranging from manually controlled hygrometers with visual detection of the dew deposit to completely automatic instruments in which the thickness of the dew is measured by observing the energy attenuation of alpha radiation passing through it.

Section III, Electrical Hygrometry, consists of 19 papers describing sensors that change their resistance, capacitance, or both, in response to relative-humidity changes. There is an almost bewildering array of these relative-humidity sensors available, and since none has yet demonstrated its superiority over all others for all purposes, this collection of papers describing the characteristics of most sensor types in a single volume is useful.

Section IV, Spectroscopic Hygrometry, contains 7 papers all by North American authors; one is on the absorption of radiation by water vapour, the remaining 6 describe measuring systems. The exaggerated claims of accuracy and sensitivity of spectroscopic systems that were common a few years ago are no longer made and reasonable assessments of the advantages, disadvantages and possibilities of these systems are presented. The papers leave no doubt that the long-path infra-red hygrometer is a useful instrument when a special average of humidity is required or that the Lyman-Alpha hygrometer has no equal when fast response at low dew-points is required and cost, complexity and stability of calibration are of secondary importance.

Section V, Coulometric Hygrometry, contains 4 papers describing the phosphorus-pentoxide electrolytic hygrometer. Three of the papers discuss humidity measurement in air, the fourth deals with the detection of moisture in

refrigerants. The difficulties of operating the cells over a very large range of dew-point are discussed (cells suitable for detecting dew-points of -80°C tend to overheat at surface ambient dew-points) and a method of operation employing a diffusion barrier at high dew-points is described in one paper.

Section VI, Miscellaneous Methods, contains 16 papers describing sensors ranging from chemical spots on blotting paper that change colour at a given relative humidity ± 5 per cent, to a dew-point instrument employing a single ionic crystal for which a precision of 0.01°C is claimed. The papers in this section with the greatest immediate interest to the meteorologist are 2 on hair as a humidity sensor and 2 on the lithium-chloride, heated hygrometer, since instruments employing these sensing methods are in regular use at synoptic stations.

The publishers say that "This volume forms a complete reference work on instrumentation for water vapour measurement"; this is a bold claim which the book almost substantiates. However, as one must expect, work carried out in the U.S.A. dominates and there are no papers originating in the U.S.S.R. It is rather more surprising that there is no paper on the microwave refractometer, this instrument being mentioned only briefly in one paper.

In a book with papers by more than 60 different authors the scientific quality of the work and the style of presentation obviously varies widely and it is worth remembering, when one is comparing the performance claimed for one instrument with that of another, that some of the authors represent manufacturers hoping to sell their products.

In spite of these shortcomings the book is a very welcome addition to the literature on humidity measurement. It will be of interest to the meteorologist who is concerned about the accuracy of the basic information he uses and is essential reading for anyone responsible for selecting instruments for humidity measurements.

W. R. SPARKS

Atmospheric processes in the high latitudes of the southern hemisphere, by P. D. Astapenko. $9\frac{3}{4}$ in \times $6\frac{3}{4}$ in, pp. ix + 286, *illus.* (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1-5 Portpool Lane, London EC1, 1964. Price: 63s.

This comprehensive book provides a further advance in the knowledge of the meteorology of the Antarctic continent consequent upon the analysis of data collected during the first year of the International Geophysical Year (IGY). Previously, meteorologists who had written on the subject were perforce limited to using much fragmentary data, many gaps being filled by deduction and imagination. The book does much to clear up areas of doubt and reconcile divergent views. Thus it is conclusively demonstrated that the weather over the Antarctic continent can be largely attributed to the penetration of depressions from the ocean areas and that the Antarctic anticyclone is often comparatively weak and capable of displacement at any time of the year. This permits frontal systems associated with oceanic depressions to cross the coastline and penetrate to the polar plateau and beyond. The zonal flow over the ocean areas is by no means regular and is frequently upset by extensions of the sub-tropical anticyclones, causing depressions to be channelled to

the high latitudes. So much has been deduced previously by other authors but the degree of importance to be attached to meridional flow has never before been so conclusively demonstrated.

The book fully amplifies the difficulties facing a forecaster in high southern latitudes and on early acquaintance he can be readily baffled since much of the surface data is totally unrepresentative of the true synoptic situation. This is due to the topography which is particularly mountainous and surmounted by a thick ice-cap. Forecasting demands the employment of techniques of vertical structure analysis which are often shown to be much more effective than conventional synoptic analysis. Any meteorologist required to forecast in or near the Antarctic continent will find previous study of this book invaluable.

In the final chapter, certain questions relating to the general circulation of the atmosphere are discussed together with the role which the Antarctic continent plays in the problem of long-range forecasting. Considerations and comparisons of the southern hemisphere circulation are demonstrated as being most important to the northern hemisphere problem, but the author rejects any suggestion that the Antarctic continent itself plays a greater part in the consideration than any other continent of similar size and asks the naive question "Does the presence of continents really deserve the importance attributed to it to-day"? The comparative weakness of the anticyclone compared with similar continental anticyclones which form over frigid lands in the northern hemisphere may well justify the asking of this question. It leaves the impression that it was unfortunate that the efforts during the IGY were not, or could not be, matched by corresponding large-scale efforts over the southern oceans using weather ships and survey vessels.

The book appears to lose nothing in translation, the style being easy and the text readily comprehensible. Readers not familiar with the Antarctic may well find the need of more detailed maps giving place names and topography.

G. P. BRITTEN

LETTER TO THE EDITOR

551.507.22:551.526.6

The measurement of sea surface temperature

With reference to Mr. M. W. Stubbs' article,¹ it is desirable to explain why a canvas bucket is used for measuring sea temperature aboard the British Weather Ships, when on station, and an insulated bucket when on passage. The insulated bucket is described in the Marine Observer's Handbook² and has been shown to be very accurate. It contains only a small water sample, and depends for its accuracy upon its double skin of rubber and upon the circulations which are quickly set up in the inner spaces of the double-skinned bucket when it is dragged through the water at the speed of the ship. It was specially designed for use aboard voluntary observing merchant ships, to eliminate the errors due to the minor delays that inevitably occur between immersing a thermometer in the water and taking the actual readings. One such delay is due to the relatively large height that the bucket has to be hove up from the water line to the bridge in such ships.

Ocean Weather Ships, when on station, spend most of their time lying stopped and on such occasions it is not practicable to use the insulated bucket. In these ships, the meteorologist takes his sea temperature readings on the after-deck, which is only about six feet above sea level. Using the canvas bucket he gets a large sample of water, can very quickly haul it up on deck and reads the thermometer instantly, so that a minimum of error occurs. *Meteorological Office, Bracknell.*

C. E. N. FRANKCOM

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